NASA CONTRACTOR REPORT

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CONCEPTUAL DESIGN STUDIES OF A V/STOL CIVIL LIFT FAN TRANSPORT INCLUDING EFFECT OF SIZE AND FAN PRESSURE RATIO

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16. Abstract

Conceptual design studies of V/STOL Lift Fan Commercial short-haul transport aircraft for the 1980-85 time period were studied to determine their technical and economic feasibility. The remote lift fan configurations with a variation in fan pressure ratio from 1.2 to 1.5 were investigated. Also studied were variation in stage length from 200 nautical miles to 800 nautical miles and cruise mach numbers of 0.75 and 0.85. These results indicate a four engine configuration was feasible. The 95 PNdB noise footprint would be approximately 45 acres and the DOC's would be about 60% greater than conventional transports.

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FOREWORD

The study summarized in this report is an extension of a study conducted from mid 1971 to mid 1972 entitled "Conceptual Design of a V/STOL Lift Fan Commercial Short Haul Transport" under Contract NAS2-5499. Study objectives were: (a) To investigate conceptual designs of quiet V/STOL lift fan civil short haul transports utilizing the lift fan concept; and (b) To assess suitability of near term research aircraft to provide confidence for design of a V/STOL lift fan transport aircraft for 1980-1985. The 1971-1972 study, which is presented in Reference 1, resulted in the selection of a 6 engine Remote Lift Fan (RLF) aircraft using 2 lift-cruise engines as the best compromise to satisfy the requirements for future V/STOL lift fan civil short haul transports. This study also indicated the possibility of a satisfactory 4 engine aircraft solution.

The object of the current study contract, awarded in May 1973, was to enlarge the base of civil lift fan V/STOL aircraft applications through:

(a) Update of the civil aircraft from the 1972 NASA study,

(b) Inclusion of military applications, and

(c) Investigation of common development of technology for civil and military V/STOL aircraft.

Accordingly, the previous aircraft choice (updated to new guidelines) was reexamined and compared to new candidates having different combinations of gas generators and fans of varying pressure ratios.

Performance, propulsion, stability and control, noise signatures, and direct operating cost characteristics are presented for the selected configuration. All designs considered in the evaluation employ the McDonnell Douglas Corporation patented Energy Transfer and Control (ETaC) system. In Reference 1 this concept was referred to as an (ETC) system.

SUMMARY

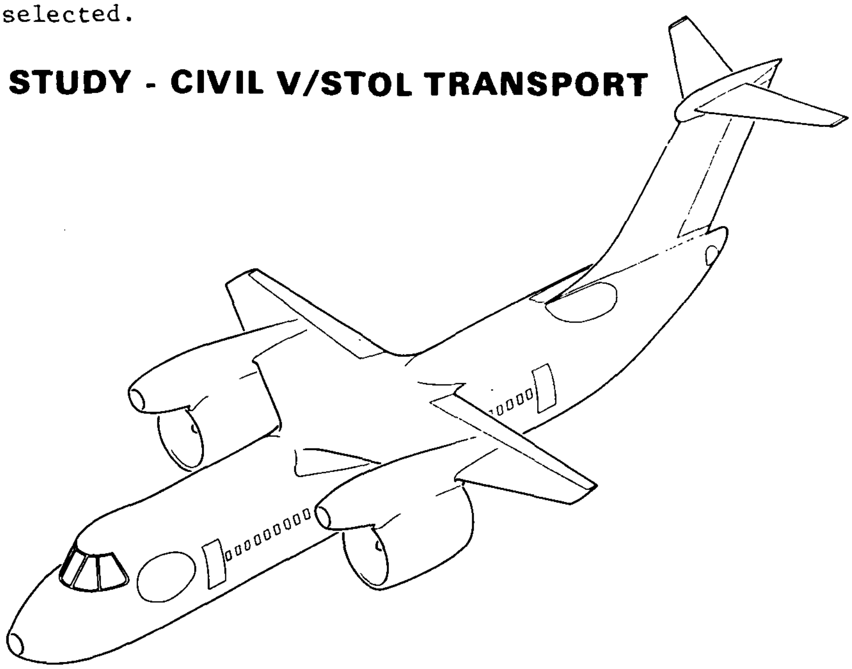
A high wing 4 engine aircraft with two lift-cruise engines mounted beneath the wing is selected as the best configuration to satisfy the requirements of the 1985 100 passenger lift fan transport. Gross weights for 400 nm VTOL and 800 nm STOL missions are 113,000 lb (51,250 kg) and 125,400 lb (56,870 kg) respectively.

Conceptual designs of various 4 engine civil V/STOL aircraft were evaluated. In addition, the selected 6 engine RLF aircraft from the 1972 study was updated to the new guidelines for evaluation and comparison with the selected 4 engine aircraft. All configurations featured gas interconnection of propulsion units for lift, propulsion, and control as well as for operational safety in the event of failure of an engine or fan. Propulsion system performance was based on that used in the previous NASA study (1972) as published in Reference 1. Higher fan pressure ratios were permitted in the 1973 study and propulsion system sizing took full advantage of energy transfer and control (EtaC). Task 1 aircraft were sized by the mission requirements including 100 passenger payload, stage lengths of 400 nm (740 km) VTOL and 800 nm (1480 km) STOL, and cruise speed of 0.75 Mach. The Task 2 aircraft were sized by a stage length of 200 nm (370 km) VTOL with the fan out safety requirement deleted.

Nine aircraft configurations using 4 engines were identified for evaluation. Variations included high and low wing, four and six lift fans, use of roll control fans, and tandem as well as side by side fans in the fuselage. Both two and four lift cruise engines were considered. Also, variations in method of achieving yaw control were evaluated.

Sufficient parametric design and performance analyses and layouts for each configuration were made within the guidelines to establish a basis for comparison and to reduce the number of configurations within each aircraft family. Contending configurations were continuously refined and evaluated until a best compromise aircraft was selected.

1973 STUDY - CIVIL V/STOL TRANSPORT



When compared to the updated 6 engine aircraft, the 4 engine aircraft shows better economics as well as operational suitability although the gross weight is somewhat higher. The sideline noise level at 500 ft (150 m) is estimated to be 98.8 PNdB, and the footprint area at 95 PNdB is approximately 44 acres (0.178 sq km).

The study results show that a 4 engine V/STOL aircraft cruising on two engines is a good match for a cruise speed between Mach 0.75 and 0.85, and because of the system simplicity, results in a configuration with inherently high dispatch reliability and safety.

The study results show that there is no economic advantage by increasing cruise speed from Mach 0.75 to 0.85; takeoff gross weight is increased by approximately six percent, and flyaway cost by approximately 4 percent. Direct operating cost and noise level also increase slightly. Some advantage in DOC is accrued when operating the 0.75 M cruise aircraft to the maximum cruise speed available, approximately 0.80 M, rather than limiting the cruising speed to 0.75 M. An 0.80 M cruise capability for the 4 engine aircraft results from the T/W installed for VTO operation.

The same 4 engine configuration was also selected for the 200 nm (370 km) stage length mission. Essentially no advantage in reduced gross weight is gained when designing the aircraft to cruise at 0.65 M instead of 0.75 M. Therefore, there is no advantage in cruising at lower speed since higher direct operating cost will result. A significant improvement results from deletion of the fan-out safety requirement through simplification of the propulsion system, i.e., elimination of four valves as well as the four emergency jet nozzles and associated controls. This reduces the gross weight approximately 2 percent. The area enclosed by the 95 PNdB noise contour is reduced by approximately 10 percent compared to the aircraft designed for the 400 nm (370 km) stage length mission.

The design and nominal takeoff fan pressure ratios chosen for the current civil aircraft are 1.39/1.30 respectively, as opposed to the 1.25/1.19 values used for the 1972 study. This minimizes gross weight, initial cost, and operating cost with minor influence on the noise footprint area.

Direct operating costs were examined over a range of values from $90 to $110 per pound of airframe weight and 2500 to 3500 hours annual utilization. DOCs are estimated as follows:

200 nm (370 km)	3.23¢/seat statute mile	(2.01¢/seat km)
400 nm (740 km)	2.57¢/seat statute mile	(1.60¢/seat km)
800 nm (1480 km)	2.14¢/seat statute mile	(1.33¢/seat km)

The DOC quoted for the 200 nm stage length applies to an aircraft designed specifically for the 200 nm VTOL mission. Costs are in 1974 dollars. The Task 1 aircraft designed for the 400 nm VTOL and 800 nm STOL missions can accomplish the 200 nm mission at a DOC increase of 3% over the aircraft specifically designed for the mission.

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SYMBOLS

a_x	acceleration
AIA	Aircraft Industries Association
AR	Aspect Ratio
BPR	By-Pass Ratio
b	Wing span, ft (m)
CG, cg	Center of gravity
C_L	Lift coefficient
$C_{L_{MAX}}$	Maximum lift coefficient
CTOL	Conventional takeoff and landing
cm	centimeters
DOC	Direct Operating Cost
ETaC	Energy Transfer and Control
FAR	Federal Air Regulation
KIAS	Indicated airspeed in knots
KTAS	True airspeed in knots (km/hr)
kg	kilogram(s)
km	kilometer(s)
kts	knots
LB; lb	pound(s)
L/C	Lift cruise
ℓ	liter
M	Mach Number
M/I	Moment/Inertia, rad/sec^2
M_{MAX}	Maximum Mach number
m	meter

NM, nm	Nautical mile(s)
N_f	Lift fan speed
N_g	Gas generator speed
OWE	Operating weight empty, lb (kg)
PAX	Passenger
PNL	Perceived Noise Level (PNdB)
psf	pounds per square foot
R/D	Rate of Descent
RLF	Remote lift fan
R_f	Fan pressure ratio
S	Area, ft^2, m^2
SAS	Stability augmentation system
SLS	Sea level standard
ST MI, st mi	Statute mile
STO	Short takeoff
STOGW	Short takeogg gross weight, lb (kg)
STOL	Short takeoff and landing
S_w	Wing area, ft^2 (m^2)
T	Gross thrust, lb (kg)
TOGW	Takeoff gross weight, lb (kg)
T/W	Thrust-to-weight ratio
t	Time, sec, min, hr
t/c	Airfoil thickness ratio
V	Velocity, knots, (km/hr)
V/STOL	Vertical/short takeoff and landing

VTO	Vertical takeoff
VTOL	Vertical takeoff and landing
W/S	Wing loading, psf, (kg/m^2)
δ_F	Flap angle
δ_R	Resultant thrust vector angle
ζ	Damping coefficient
Λ	Sweep angle, degree
$\Lambda_{c/4}$	Sweep angle of quarter chord, degree
λ	Wing taper ratio
ω_n	Undampened natural frequency, rad/sec
θ	Deck angle

1. INTRODUCTION

In accordance with the NASA statement of work the contractor reviewed the previously selected remote lift-fan commercial transport design in the 1972 study, and modified the design as required to be representative of the contractor's present views of the best 1985 remote lift fan transport. Lift fan pressure ratios greater than 1.25 were considered as well as gas generator-fan combinations other than one gas generator per fan.

Section 6 of Reference 1 discusses the tradeoffs of gross weight versus operational advantages in transports with reduced number of engines. Particularly, dispatch reliability is enhanced as the number of engines are reduced. The study also indicated the possibility of a 4 engine transport satisfying the requirements. Therefore great emphasis was applied in the current study to achieving a 4 engine aircraft solution to this problem.

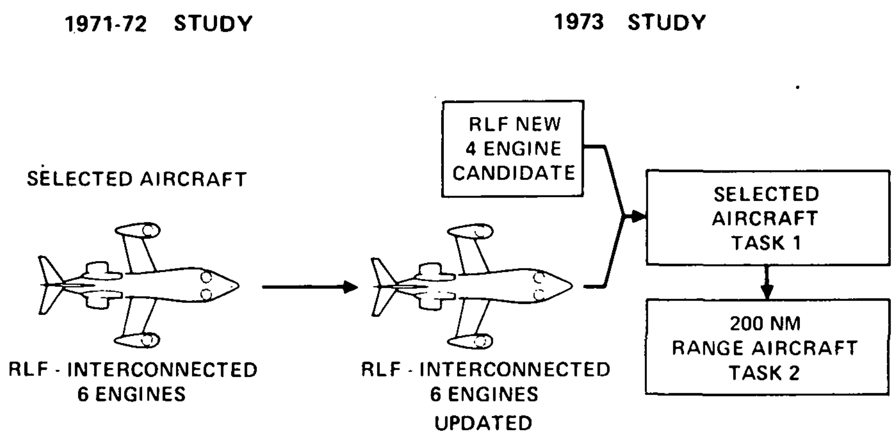
Advantage was taken of recent NASA/MCAIR and MCAIR developments in flight simulation, thrust vectoring systems, valve and duct designs, aerodynamic/propulsion interference characteristics, and noise analysis.

Figure 1-1 shows the interrelationship of the 1972 and 1973 study programs and the major tasks performed in the current study. This volume reports the results of the following two basic tasks:

Task 1 - Conceptual design of a 100 passenger civil transport with a VTOL range of 400 nm (740 km) and STOL range of 800 nm (1480 km) while cruising at Mach - 0.75 (Task 1A) and at 0.85 (Task 1B).

Task 2 - Conceptual design of a 100 passenger civil transport with a VTOL stage length of 200 nm (370 km) while cruising at Mach = 0.75 (Task 1A) and at 0.65 (Task 2B). Fan-out operation is not required.

FIGURE 1-1
NASA V/STOL LIFT FAN AIRCRAFT STUDIES



This report summarizes the design selection process as well as the characteristics of the selected designs, including performance, propulsion, control, noise and economic data.

The design criteria, mission requirements, and guidelines which served as the basis for this study are outlined in Appendix A. The 1972 study requirements are also included for comparison. Guideline requirements having a major impact on the design are identified together with the specific aircraft characteristics affected. Resultant differences between the 1972 and 1973 aircraft selections are summarized, including a six engine design updated to the 1973 guidelines.

The selection process used in determining the best 4 engine configuration is described in Appendix B. Qualitative and quantitative design considerations and evaluation parameters governing the designs and selection are also discussed. As indicated in the configuration matrix (Figure B-1), the VT107-4-4I was selected as the best 4 engine candidate.

Appendix C summarizes the characteristics of the 1972 6 engine aircraft updated to the 1973 guidelines for a direct comparison with the selected 4 engine design.

Appendix D is a final evaluation summary and comparison of the 4 and 6 engine aircraft sized for the missions.

2. AIRCRAFT SELECTION

2.1 SELECTED 4 ENGINE AIRCRAFT

The final sized VT107-4-4I is shown in Figure 2-1. Two interconnected lift-cruise engines installed beneath the wing provide lift and roll control in the V-mode of operation and thrust for transition and cruise. Two interconnected lift engines one in the nose and the other in the aft fuselage provide lift, longitudinal, and directional control during the low speed flight regime. The major elements of the lift/propulsion/control system are illustrated in Figure 2-2. Figure 2-3 is a schematic of the propulsion system showing interconnect ducts between engine pairs, also types and number of valves for lift, cruise, and control functions. Propulsion system size is established by the flight safety, engine out requirements, for vertical takeoff in the 400 nm (740 km) VTOL mission. The maximum fuel requirement and the structural design gross weight are established by the 800 nm (1480 km) STOL mission. Pertinent physical and performance characteristics are presented in Figure 2-4.

FIGURE 2-1
SELECTED 4 ENGINE AIRCRAFT
TASK 1A M = 0.75 VT107-4-4I

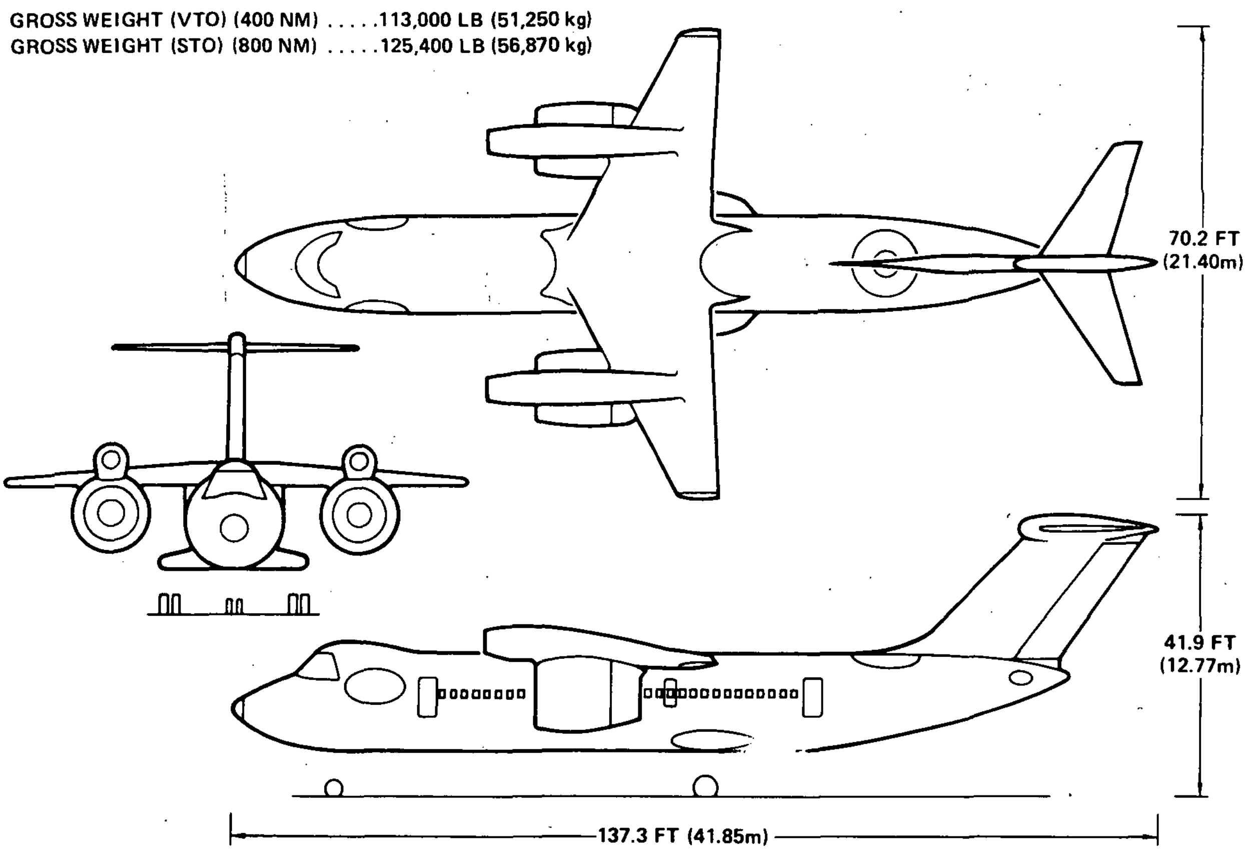


FIGURE 2-2
SELECTED 4 ENGINE AIRCRAFT PROPULSION SYSTEM
VT107-4-4I

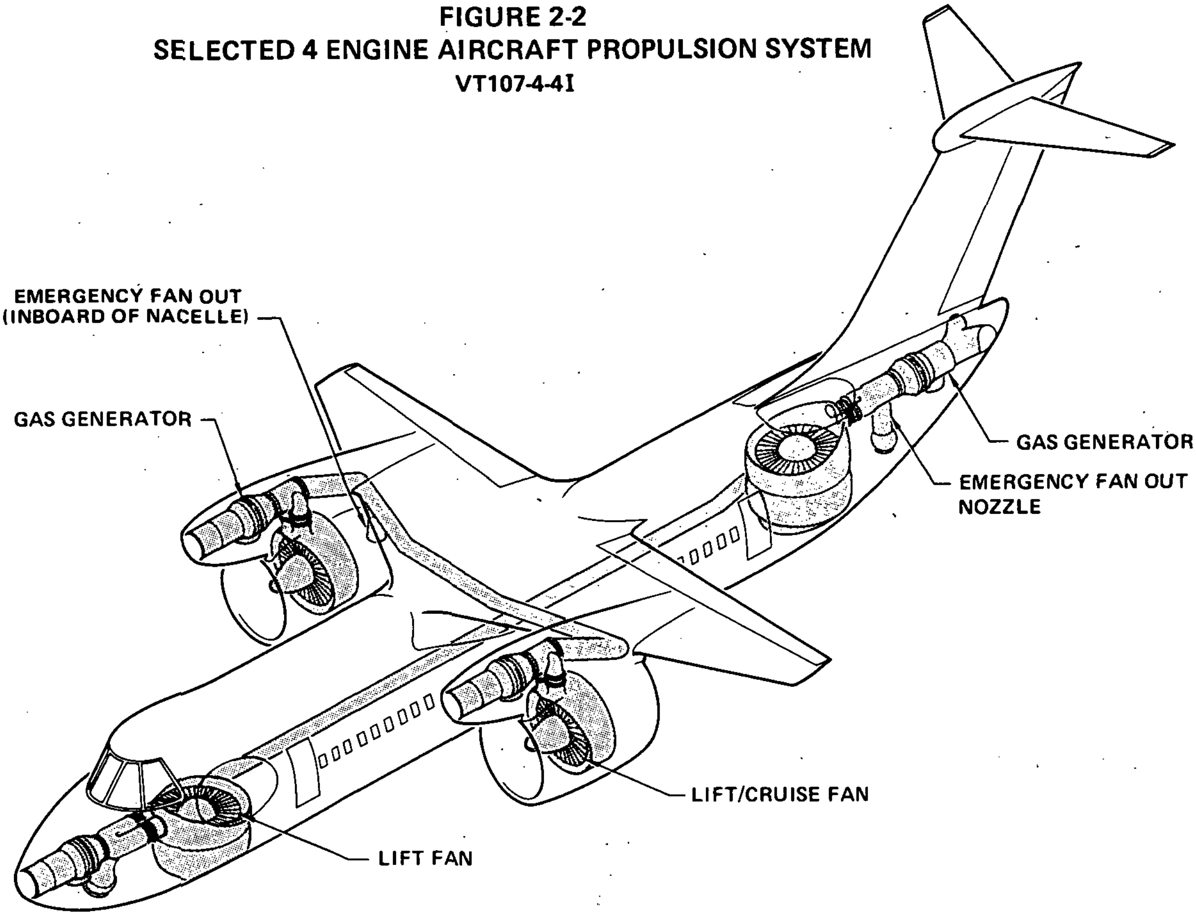


FIGURE 2-3
VT107-4-4I PROPULSION SYSTEM SCHEMATIC

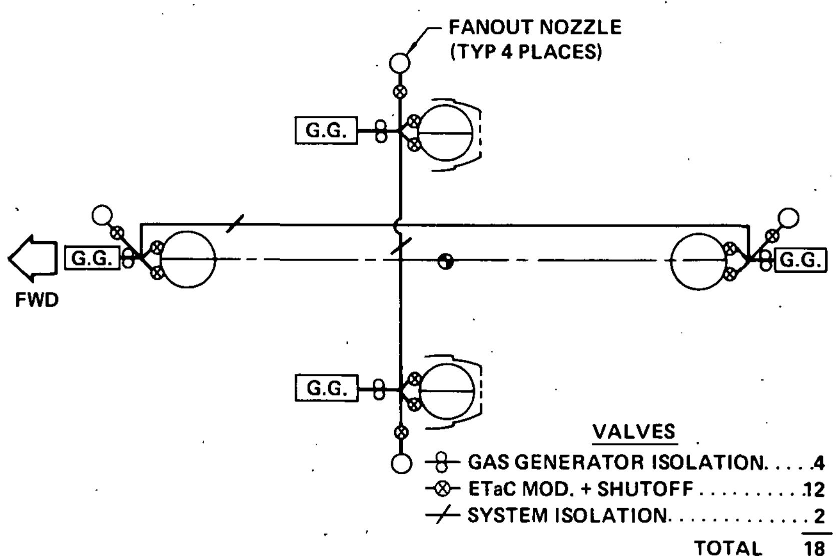


Figure 2-4

Characteristics Summary
4 Engine Aircraft - Task 1A

VTO Gross Weight 400 nm (740 km)	113,000 lb (51,250 kg)
STO Gross Weight 800 nm (1480 km)	125,400 lb (56,870 kg)
Wing Loading at VTOGW	115 psf (560.0 kg/m^2)
Design Fan pressure Ratio	1.39
Engines	4
Fan Diameter	97.9 in (2.49 m)
Nominal T/VTOGW at 90°F SL	1.20
% Modulation for Control (maximum)	28
Payload (100 passengers)	20,000 lb (9,072 kg)
Cruise Mach at 30,000 ft (9140 m)/V_{CRUISE}(MAX.)	0.75/0.80
500 ft (150 m) Sideline Noise Level PNdB	98.8

Direct Operating Cost (1974 Dollars, Airframe $90/lb, 3500 hr/yr Utilization)

400 nm (740 km)	2.57¢/seat statute mile (1.60¢/seat km)
800 nm (1480 km)	2.14¢/seat statute mile (1.33¢/seat km)

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S	983 ft^2 (91.3 m^2)	262 ft^2 (24.3 m^2)	400 ft^2 (37.2 m^2)
AR	5	5	0.94
λ	0.25	0.35	0.76
b	70.17 ft (21.39 m)	36.20 ft (11.03 m)	19.40 ft (5.91 m)
Λ C/4	22°	30°	44°
t/c	16% FUS ℄, 12% TIP	8%	11%
AIRFOIL	Whitcomb Type Supercritical	DC-9 Type Empennage	DC-9 Type Empennage

The interior arrangement and cross section of the passenger compartment are shown in Figures 2-5 and 2-6. Featured are accommodations for 100 passengers in a six abreast, 2 aisle configuration. Seats are at 34 inch spacing. Additional accommodations include two lavatories, coat racks and a food galley. Front and rear entrance doors with retractable stairways are provided as well as a spacious luggage compartment.

FIGURE 2-5
INTERIOR ARRANGEMENT
100 PASSENGERS - 34 INCH PITCH

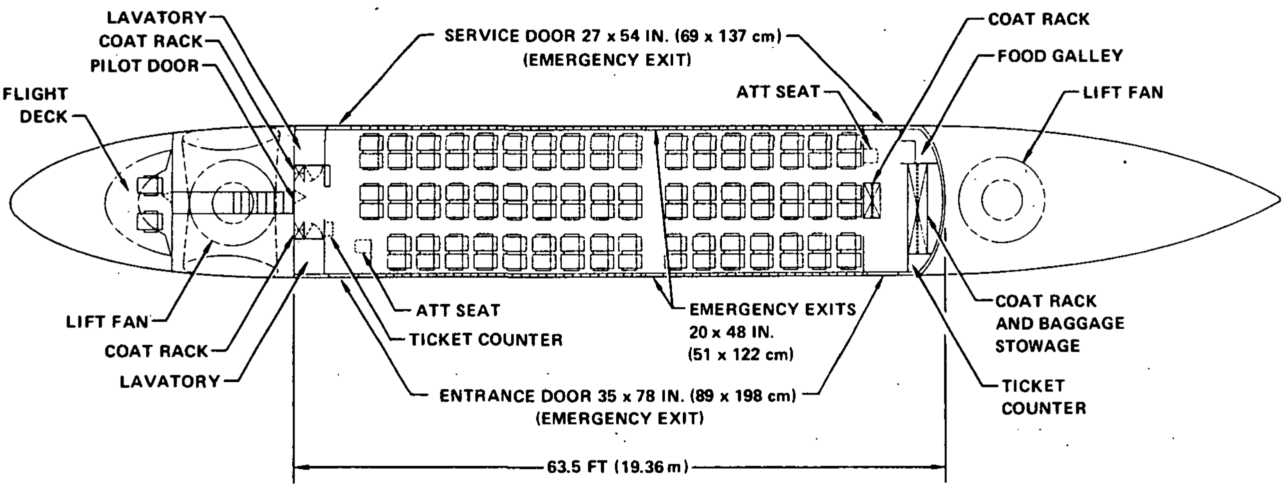
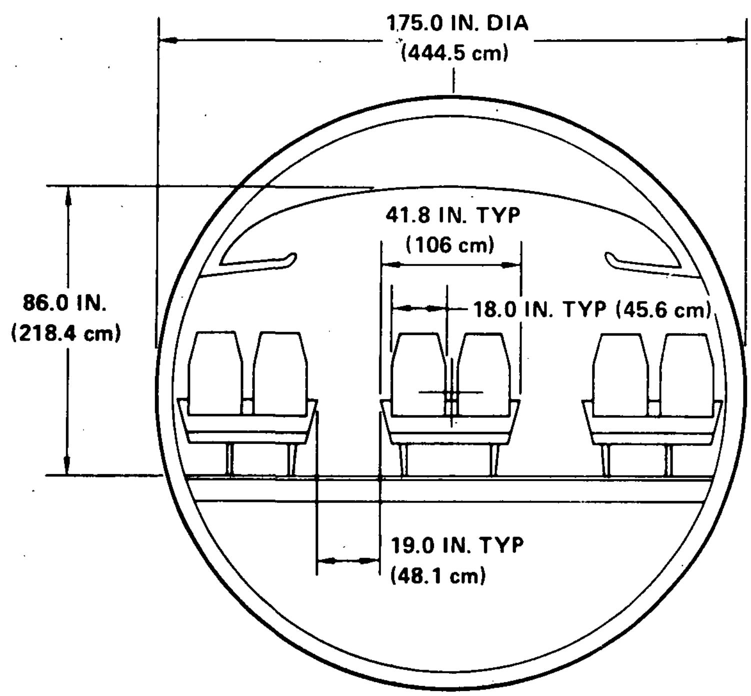


FIGURE 2-6
PASSENGER CABIN CROSS SECTION (TYP)



2.2 TASK 1B - 0.85 M CRUISE SPEED

A wing sweep angle increase from 22 degrees to 32 degrees is required to increase the cruise Mach number capability of the VT107-4-4I aircraft configuration to the desired M = 0.85 level to satisfy the Task 1B requirement. Figure 2-7 shows the resultant 0.85 M configuration, designated as VT107-4-4J. Figure 2-8 presents some of its major physical characteristics and Figure 2-9 compares characteristics of the 0.75 M and 0.85 M cruise aircraft. The propulsion system size, established by VTOL flight requirements, is a good match with cruise Mach number between 0.75 and 0.85.

FIGURE 2-7
SELECTED 4 ENGINE AIRCRAFT
TASK 1B M = 0.85 VT107-4-4J

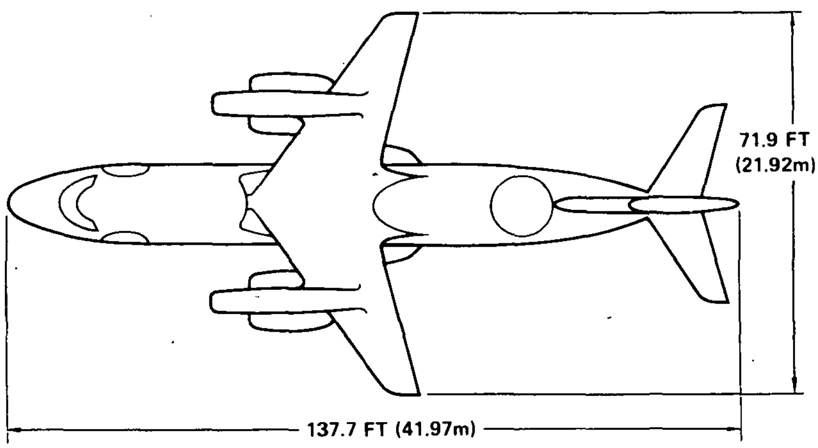


Figure 2-8

VT107-4-4J Physical Characteristics

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S	1034 ft^2 (96.1 m^2)	275.6 ft^2 (25.6 m^2)	400 ft^2 (37.2 m^2)
AR	5.0	5.0	0.94
λ	0.25	0.35	0.76
b	71.90 ft (21.91 m)	37.12 ft (11.31 m)	19.40 ft (5.91 m)
Λ c/4	32^o	30^o	44^o
t/c	16% FUS ℄, 12% TIP	8%	11%
AIRFIOIL	Whitcomb Type Supercritical	DC-9 Type Empennage	DC-9 Type Empennage

Figure 2-9
Effect of Mach Number Increase -
Task 1B - 4 Engine Aircraft

PARAMETER	VT107-4-4I M = 0.75	VT107-4-4J M = 0.85
VTOGW - 400 nm (740 km) lb (kg)	113,000 (51,250)	119,000 (53,970)
STOGW - 800 nm (1480 km) lb (kg)	125,400 (56,870)	133,400 (60,500)
OWE - lb (kg)	72,580	76,429
FAN DIAMETER - in (m)	97.9 (2.49)	100.3 (2.56)
NOMINAL T/W AT 90° SL	1.20	1.20
DESIGN CRUISE MACH NUMBER	0.75	0.85
MAXIMUM MACH NUMBER	0.80	0.85
MISSION FUEL		
400 nm (740 km) Stage lb (kg)	20,420 (9,300)	22,571 (10,250)
800 nm (1480 km) Stage lb (kg)	33,592 (15,200)	36,946 (16,700)
BLOCK TIME		
400 nm (740 km) Stage	1.095 hr	1.030 hr
800 nm (1480 km) Stage	2.014 hr	1.870 hr
DIRECT OPERATING COST - ¢/SEAT STAT. MILE (km)		
400 nm (740 km) Stage	2.57 (1.60)	2.61 (1.62)
800 nm (1480 km) Stage	2.14 (1.33)	2.16 (1.34)
NOISE LEVEL - 500 ft (150 m) SIDELINE	98.8 PNdB	99.1 PNdB

Increasing the design Mach number to M = 0.85 has the following overall effects:

DEGRADATIONS	IMPROVEMENTS
o 6% increase in takeoff weight	o Block time savings
o 10% increase in mission fuel	o 4 min for 400 nm (740 km) VTOL stage
o 6% increase in operating weight empty	o 8.6 min for 800 nm (1840 km) STOL stage
o Slight increase in DOC	
o Slight increase in noise level	

Technical characteristics are discussed further in Section 3.

2.3 TASK 2 - 200 NM VTOL STAGE LENGTH

The purpose of this task was to redesign the 100 passenger transport for a 200 nm (370 km) VTOL range at 0.75 Mach cruise speed. As indicated in the guidelines, fan out operation is not a requirement as in Task 1. For the 200 nm (370 km) range mission the weight per passenger including baggage, was specified at 180 lb (82 kg) versus the 200 lb (91 kg) for Task 1. The sensitivity to a reduced cruise speed requirement of 0.65 M was also to be determined.

The 4 engine aircraft configuration (VT107-4-4I) defined in Section 2.1 was scaled down to match the Task 2 mission safety requirements. Figure 2-10 is a three-view of the resultant aircraft (VT107-4-4K) at a gross weight of 96,400 lb (43,720 kg), and Figure 2-11 is a schematic of the propulsion system. Compared to the VT107-4-4I schematic (Figure 2-3) four fan out nozzles are removed and the total number of valves is reduced from 18 to 14. Because of the smaller fan and inlet of the forward fuselage fan it was possible to eliminate the raised cockpit. All other features of the -4I were retained. Figure 2-12 presents the pertinent physical and performance characteristics of the VT107-4-4K aircraft.

The VT107-4-4K shows little sensitivity to a reduced cruise Mach number of 0.65. A very small reduction in gross weight is possible, however, there is no advantage in cruising at lower speed since this results in higher direct operating cost.

FIGURE 2-10
SELECTED 4 ENGINE AIRCRAFT
TASK 2 M = 0.75, 200 NM VT107-4-4K

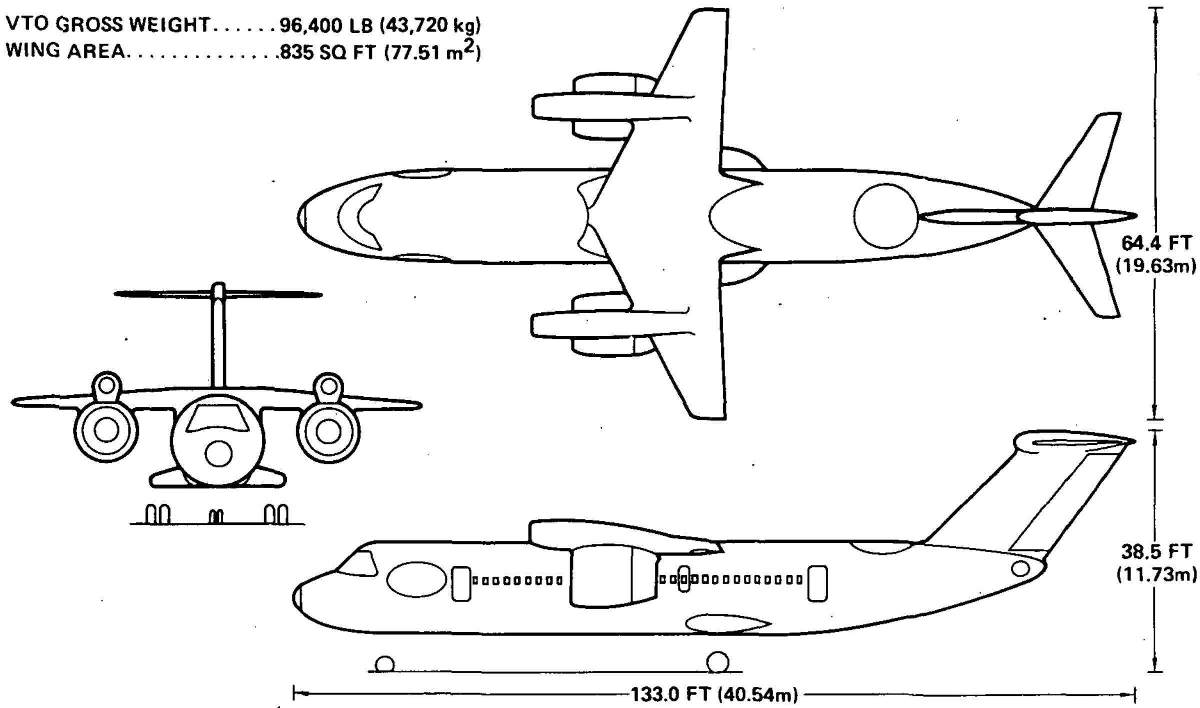


FIGURE 2-11
VT107-4-4K - PROPULSION SYSTEM SCHEMATIC

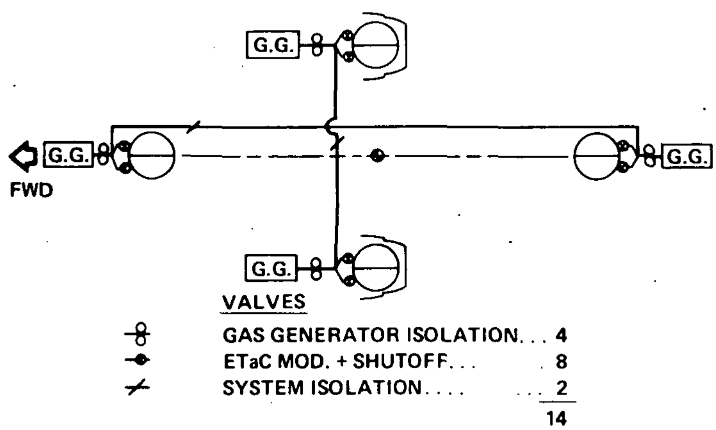


Figure 2-12

Characteristics Summary

4 Engine Aircraft - Task 2

VTO Gross Weight 400 nm (740 km)	96,400 lb (43,720 kg)
Wing Loading at VTOGW	115 psf (560.0 kg/m^2)
Design Fan Pressure Ratio	1.39
Engines	4
Fan Diameter	90.4 in (2.30 m)
Nominal T/VTOGW at 90°F SL	1.20
% Modulation for Control (maximum)	26
Payload (100 passengers)	18,000 lb (8,163 kg)
Cruise Mach at 25,000 ft (7,620 m) V_{CRUISE}(MAX)	0.75/0.80
500 ft (150 m) Sideline Noise Level PNdB	98.1
Direct Operating Cost (1974 Dollars, Airframe $90/lb, 3500 hr/yr Utilization)	
200 nm (370 km)	3.23¢/seat statute mile (2.01¢/seat km)

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S	838.3 ft^2 (77.9 m^2)	223.4 ft^2 (20.77 m^2)	400.0 ft^2 (37.2 m^2)
AR	5	5	.94
λ	.25	.35	.76
b	64.74 ft (19.73 m)	33.42 ft (10.18 m)	19.40 ft (5.91 m)
Λ c/4	22°	30°	44°
t/c	16% FUS ℄, 12% TIP	8%	11%
AIRFOIL	Whitcomb Type Supercritical	DC-9 Type Empennage	DC-9 Type Empennage

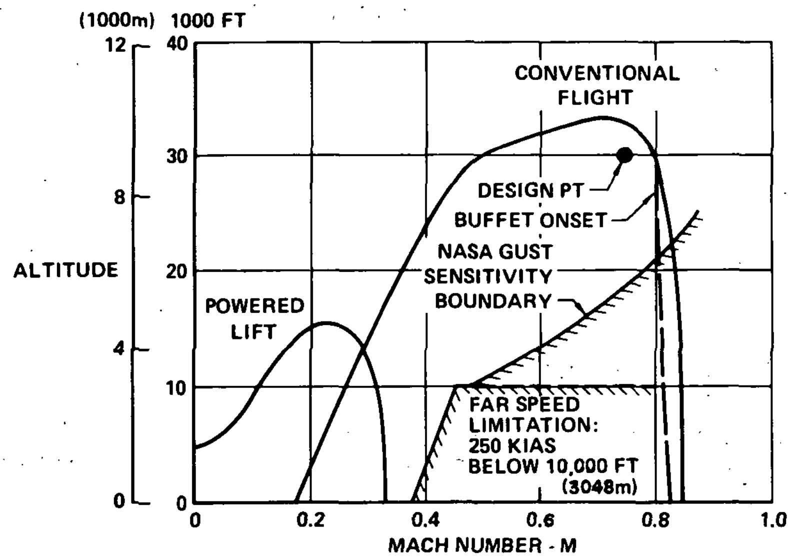
3. SELECTED AIRCRAFT CHARACTERISTICS

3.1 AERODYNAMIC PERFORMANCE

3.1.1 TASK 1 AIRCRAFT PERFORMANCE - Performance details for the selected Task 1 aircraft (flight envelope, payload versus stage length, takeoff profiles, STOL performance, conversion speed, and landing profiles) are described in the following paragraphs.

Flight Envelope - Figure 3.1-1 presents the flight envelope for both powered lift and conventional flight regimes with standard day maximum continuous thrust. With the powered lift system operating the hover ceiling is about 5,000 ft (1520 m) and the maximum level flight Mach number is approximately 0.35. The overlap zone between the powered lift flight envelope and the conventional flight envelope defines the flight conditions where the powered lift can be safely started or shut down during flight. With a safety factor of 1.3 power off stall speed, in conventional flight, this speed overlap zone allows safe conversions at altitudes up to about 9,000 ft (2740 m). For low speed operation in conventional flight (two lift cruise fans operating) the trailing edge high lift flaps are deflected to 50 degrees (stall speed is 114 KTAS (211 km/hr) at static sea level conditions). The conventional flight envelope is characterized by an absolute ceiling of 33,500 ft (10,210 m) and a maximum Mach number of 0.80 at 30,000 ft (9140 m). Climb to cruise altitude and cruise are established at Mach numbers avoiding the FAR speed limit below 10,000 ft (3040 m), the NASA gust sensitivity zones (passenger comfort) and compressibility buffet. Cruise is established at M = 0.75 (442 KTAS (819 km/hr)) at 30,000 ft (9140 m).

FIGURE 3.1-1
FLIGHT ENVELOPES
VTOGW = 113,000 LB (51,250kg)
DESIGN TASK 1A VT107-4-4I

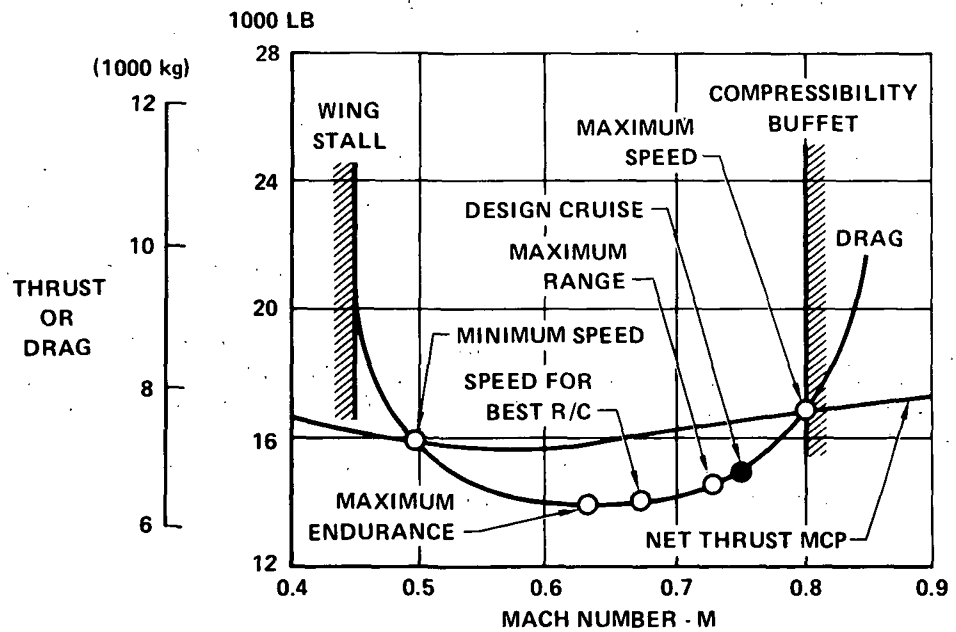


Summary of Conventional Flight Performance - Figure 3.1-2 summarizes the loiter, maximum rate of climb, cruise and maximum level flight Mach numbers at 30,000 ft (9,140 m) cruise altitude for the VT107-4-4I aircraft at a gross weight of 113,000 lb (51,250 kg). These operating conditions are tabulated below.

FLIGHT CONDITION	MACH	KTAS (KM/HR)	(L/D)
Loiter (Max Endurance)	.630	371 (688)	8.07
Maximum R/C	.673	397 (735)	8.04
Maximum Range	.730	430 (800)	7.74
Design Cruise	.750	447 (819)	7.53
Maximum Speed	.800	471 (875)	6.73

The wing stalls at a Mach number of 0.45 but minimum level flight speed is at Mach number of 0.495 because the thrust available establishes the critical limit.

FIGURE 3.1-2
PERFORMANCE SUMMARY
VT107-4-4I
VTOGW = 113,000 LB (51,250kg)
ALTITUDE = 30,000 FT (9,140m)
$(L/D)_{MAX}$ = 8.1
$(L/D)_{CRUISE}$ = 7.5



Payload Versus Stage Length - Figure 3.1-3 shows that the four fan configuration (VT107-4-4I) matches the design guideline for both a VTOL 400 nm (740 km) stage length and a STOL 800 nm (1480 km) stage length carrying a 20,000 lb (9070 kg) 100 passenger payload. The 800 nm (1480 km) STOL mission uses a STO with a vertical landing at the destination. The aircraft internal fuel tankage capacity is 32,600 lb (14,800 kg) which is sized by the 800 nm (1480 km) stage length and includes landing fuel reserves.

Takeoff Profile - Figure 3.1-4 presents the takeoff profile used to minimize noise. The time and fuel required from VTOL to a conversion speed of 153 KTAS (283. km/hr) are 82 seconds and 1,115 lb (506 kg) respectively. At the start of conversion to conventional flight, the aircraft is approximately 0.8 nautical miles (1.5 km) downrange and 1200 ft (366 m) above the terrain. The profile shown is flown with a throttle setting corresponding to a T/W = 1.05 and a deck level attitude for passenger comfort.

STOL Performance - Figure 3.1-5 shows STOL performance for the VT107-4-4I in accordance with the NASA guidelines which includes gas generator and fan failures. The takeoff field length, critical for the engine failure case, is less than 1100 ft (335 m) at a takeoff weight of 125,400 lb (56,870 kg). The short takeoff performance is based on a two position thrust vector setting to take advantage of the best angle for ground roll acceleration ($\delta_R = 23^o$) and the best angle for lift off and climb out to 35 ft (10.7 m) ($\delta_R = 53^o$). A normal 4 engine takeoff to an altitude of 35 ft (10.7 m) following FAA prescribed safety restrictions, requires about 800 ft (244 m) and 9 seconds. The V_2 safety speed at 35 ft (10.7 m) threshold is 84 KTAS (155.7 km/hr). The landing field length at takeoff gross weight is approximately 1100 ft (335 m) giving balanced takeoff and landing performance. The short landing performance is based on an approach rate of 800 fpm (4.06 m/sec). The approach conditions for normal operation at a gross weight of 125,400 (56,780 kg) are:

Flight path angle	-7.5^o
Approach airspeed	60 KTAS (111 km/hr)
Throttle setting	93% of maximum continuous power
Resultant thrust vector angle	88^o from fuselage reference plane

Conversion Speed - The 4 engine configuration has an estimated "lift system on" maximum speed capability in excess of 230 KTAS (426.0 km/hr) at STOGW. Figure 3.1-6 shows the transition speed overlap capability with full span double slotted flaps ($C_{LMAX} = 2.6$). The minimum required conversion speed is in the order of 160 KTAS (296.0 km/hr) with a 30% speed safety margin. This provides a margin of 37 KTAS (68.6 km/hr) from stall at the STO gross weight.

FIGURE 3.1-3
PAYLOAD - STAGE LENGTH
DESIGN CRUISE ALTITUDE - 30,000 FT (9,144m)
DESIGN CRUISE M = 0.75
DESIGN TASK 1A VT107-4-4I

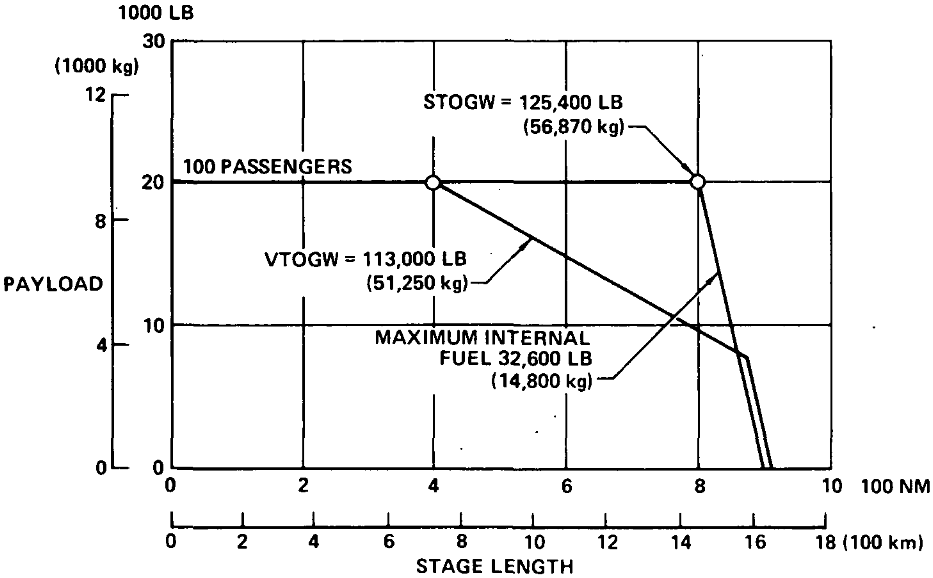


FIGURE 3.1-4
TAKEOFF PROFILE
SEA LEVEL 90°F (32.2°C)
VT107-4-4I

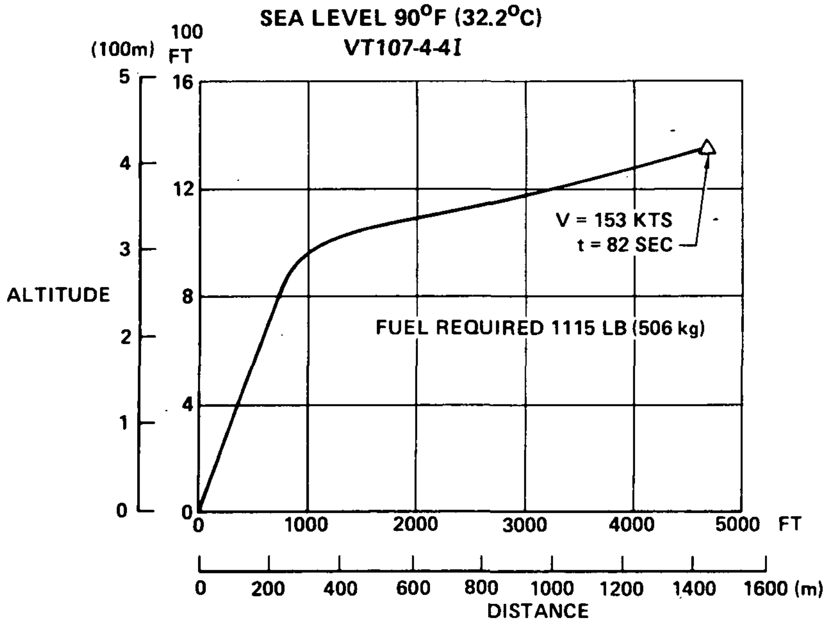


FIGURE 3.1-5
TAKEOFF AND LANDING FIELD LENGTHS
DESIGN TASK 1A VT107-4-4I

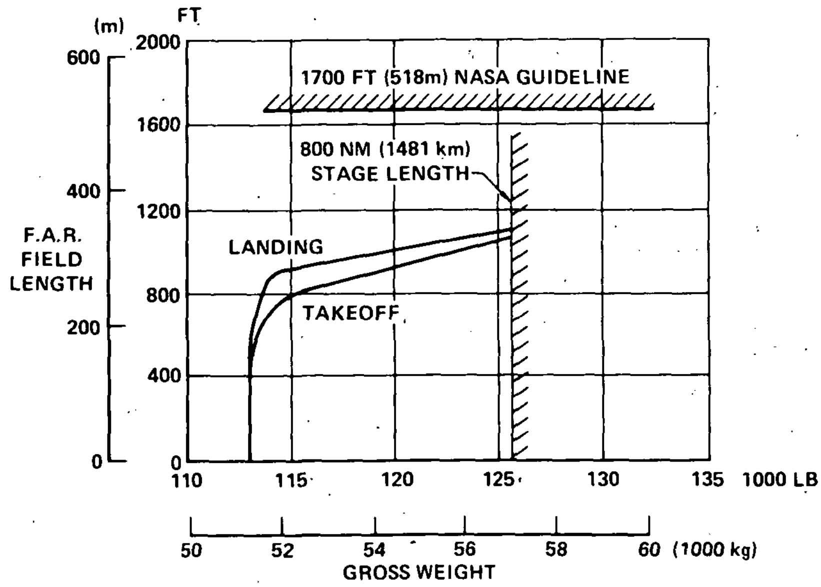
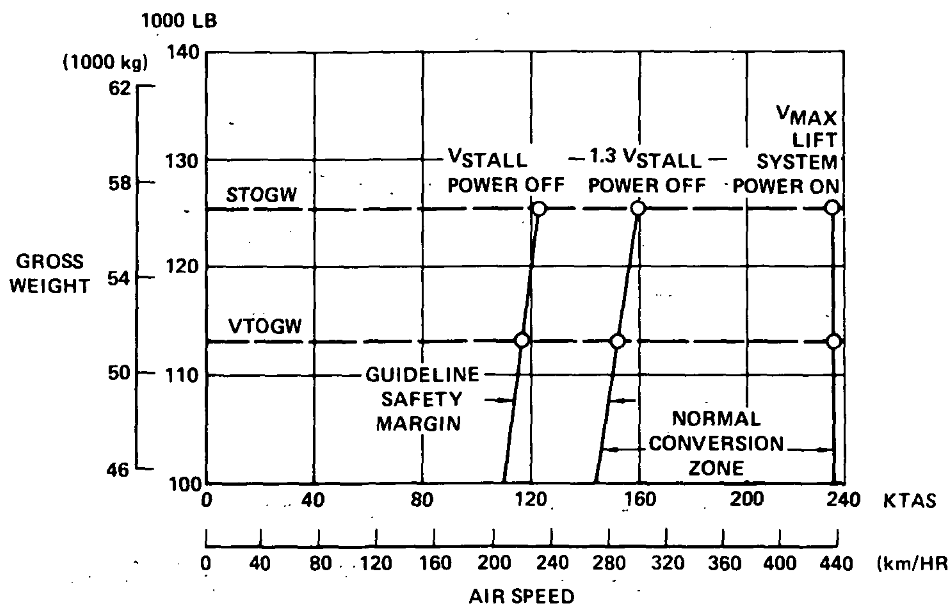


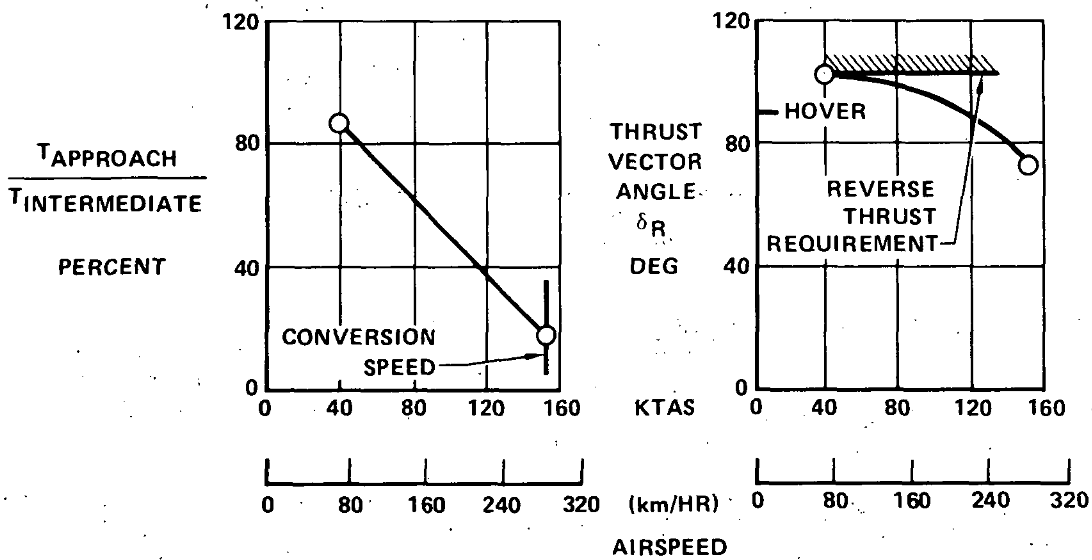
FIGURE 3.1-6
TRANSITION SPEED OVERLAP
VT107-4-4I SEA LEVEL 90°F (32.2°C)



Descent Capability - The NASA guidelines require a steep descent capability equivalent to a rate of descent of 2,000 fpm (10.16 m/sec) with a 0.15g deceleration along the flight path at maximum landing gross weight in the speed range from 40 KTAS (74.1 km/hr) to conversion speed with a 25 knot (46.4 km/hr) crosswind. Combining the requirements for a constant rate of descent and a constant level of deceleration for a maximum landing gross weight of 125,400 lb (56,870 kg) results in the curved flight path approach. The application of this steep approach capability is not operational near the ground because of the high level of touchdown rate of sink. This capability is considered a design level to establish reverse thrust vectoring requirements. A practical curved path approach is shown in the section titled "Landing Profiles".

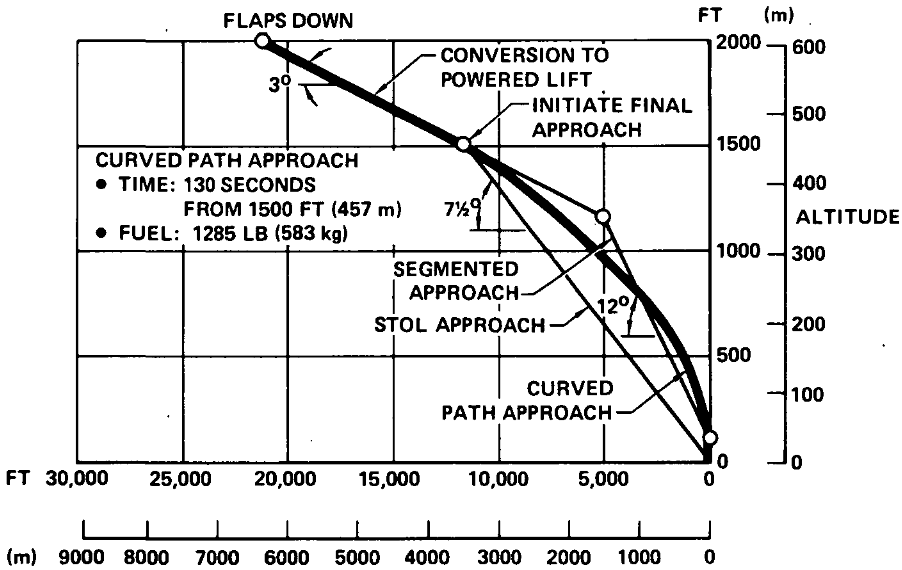
The throttle settings and thrust vectoring angles necessary to fly the design curved path approach is shown in Figure 3.1-7. The design reverse thrust vector angle for the VT107-4-4I occurs at the lowest airspeed and is 102° or 12° beyond hover position (90°). The reverse thrust angle requirements and throttle settings are within the limits of the aircraft.

FIGURE 3.1-7
STEEP DESCENT CAPABILITY
VT107-4-4I
GW = 125,400 LB
R/D = 2,000 FPM (10.16 m/SEC)
$a_x = -0.15G$



Landing Profiles - The three landing profiles shown on Figure 3.1-8 have been flown under simulated IFR conditions during MCAIR studies using a moving base simulator (Reference 2). The curved path approach is selected as most representative for 1985 V/STOL transports. The curved path approach provides a comparatively higher altitude above the terrain during the final 0.5 nautical mile (0.93 km) to touchdown which results in lower ground noise. The flight time and fuel requirements shown on Figure 3.1-8 are based on time histories from the flight simulator. The landing approach from an altitude of 1500 ft (450 m) begins approximately two nautical miles (3750 m) from the touchdown point.

FIGURE 3.1-8
LANDING APPROACH PROFILE
MCAIR SIMULATOR STUDY



3.1.2 TASK 1B AIRCRAFT PERFORMANCE - The aircraft selected for Task 1B, VT107-4-4J, is described in Section 2.3. The design cruise condition for this aircraft is M = 0.85, 500 KTS (926 km/hr) at 30,000 ft (9140 m). The flight envelope and payload versus stage length characteristics of the aircraft are similar to that shown for the Task 1 VT107-4-4I aircraft (Figures 3.1-1 and 3.1-3).

3.1.3 TASK 2 AIRCRAFT PERFORMANCE - The aircraft selected for Task 2, VT107-4-4K, is described in Section 2.4. Figure 3.1-9 presents the conventional flight envelope of the aircraft at the VTOGW of 96,400 lb (43,730 kg). The cruise conditions are established at M = 0.75 and 25,000 ft (7620 m). The flight envelope is characterized by an absolute ceiling of approximately 32,000 ft (9750 m) and a maximum Mach number of M = 0.81 at 25,000 ft (7600 m). The NASA gust sensitivity boundary can be a factor in limiting low altitude high speed cruise capability for off design operations on stage lengths less than 200 nm (370 km). The NASA gust sensitivity boundary is exceeded at M = 0.75 cruise at altitudes lower than 18,000 ft (5490 m). Figure 3.1-10 presents payload versus stage length characteristics of the VT107-4-4K aircraft. The mission fuel requirement is 13,400 lb (6080 kg) and the fuel tankage is established at that level.

FIGURE 3.1-9
CONVENTIONAL FLIGHT ENVELOPE
VTOGW = 96,400 LB (43,720kg)
DESIGN TASK 2A VT107-4-4K

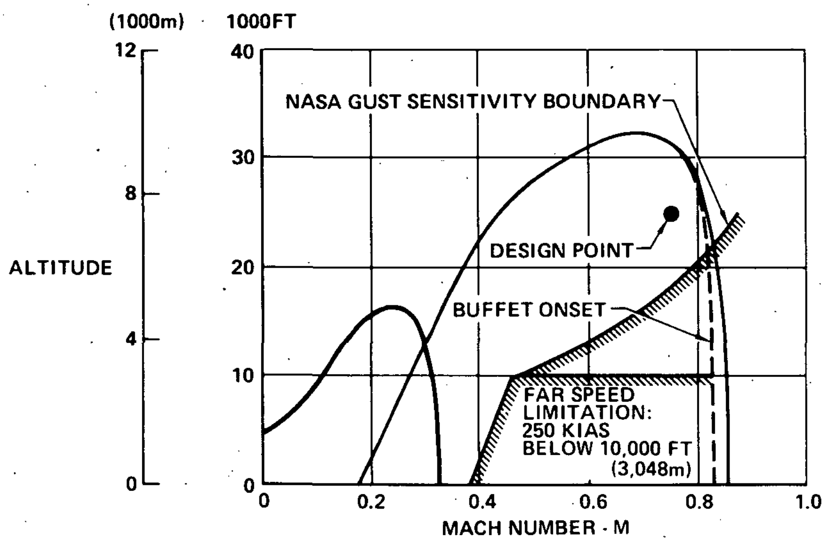
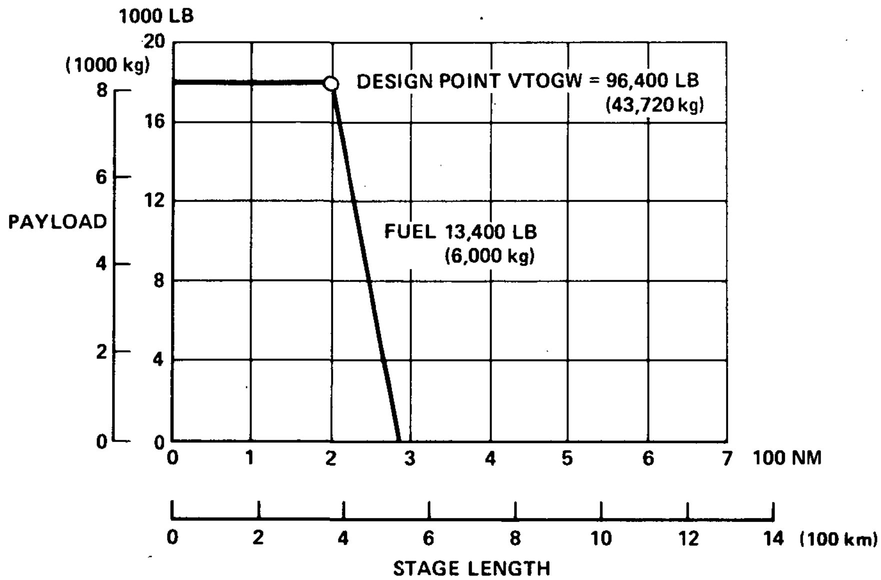


FIGURE 3.1-10
PAYLOAD - STAGE LENGTH
100 PASSENGERS M = 0.75
DESIGN TASK 2A VT107-4-4K



3.2 PROPULSION

The propulsion system utilizes the General Electric turbotip remote lift fan (RLF) engine system shown in Figure 3.2-1. The baseline fan and gas generator designs and performance characteristics are furnished by General Electric Company (Reference 5). The selected aircraft propulsion system includes four RLF engines gas connected in pairs as shown in Figure 3.2-2. All four fans are used to produce the necessary lift and attitude control forces during VTOL. The two wing mounted units are used to produce thrust for conventional flight. Gas transfer between the RLF system is accomplished with the Energy Transfer and Control (ETaC) system. A discussion of the ETaC system and the principles for modulating thrust is contained in Reference 1. Vectoring systems at each fan exit complete the propulsion/lift system. This system offers efficient utilization of the power generated during both VTOL and conventional flight through a combination of gas transfer between gas generators and fans so that all lift, attitude control during VTOL and thrust for transition to conventional flight is provided without additional systems. In addition, the system allows redistribution of power to the fans and/or emergency nozzles as required for engine out operation.

3.2.1 PROPULSION SYSTEM SIZING - Figure 3.2-3 presents design characteristics of the gas generator and fan. The performance and sizing charcteristics of the fans in the current study were obtained by adjusting the characterisitcs of the Reference 5 study fan. Figure 3.2-4 presents the sized propulsion system data for the VT107-4-4K, VT107-4-4J, and VT107-4K aircraft.

FIGURE 3.2-1
REMOTE FAN ENGINES

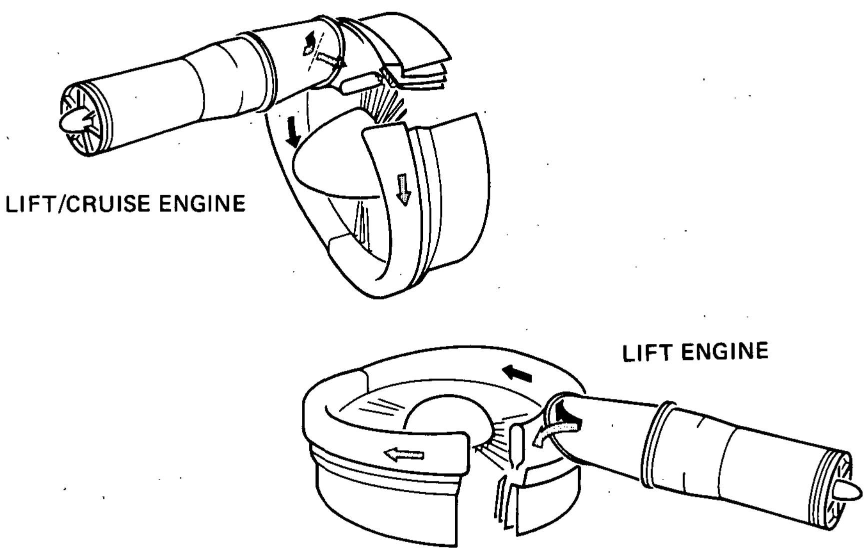


FIGURE 3.2-2
PROPULSION SYSTEM
VT107-4-4I

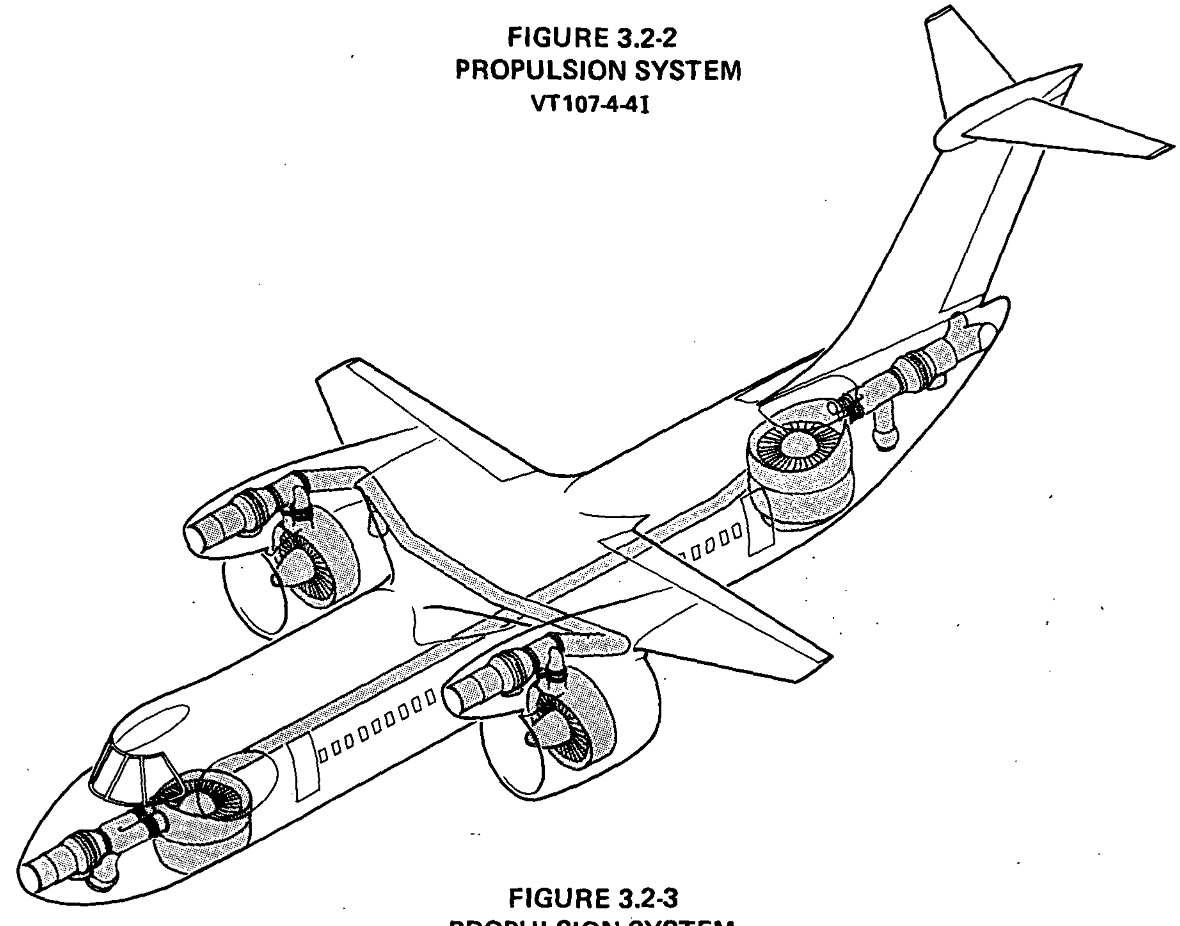
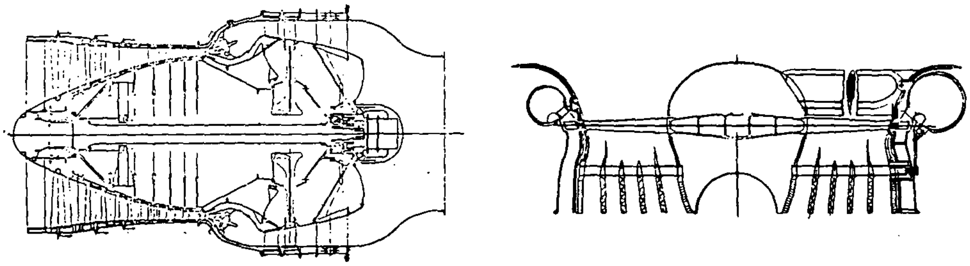


FIGURE 3.2-3
PROPULSION SYSTEM

TURBOJET GAS GENERATOR | TURBOTIP FAN



DESIGN CHARACTERISTICS

SINGLE SPOOL TURBOJET	SINGLE STAGE FAN
SEVEN STAGE VARIABLE STATOR COMPRESSOR	SINGLE STAGE TURBINE
SINGLE STAGE TURBINE	ROTOR-STATOR SPACING AND SPLITTERS INCLUDED TO REDUCE NOISE

CYCLE CHARACTERISTICS AT DESIGN POINT
(SLS, STD DAY, 100% RPM)

			VT-107-4-4
COMPRESSOR PRESSURE RATIO	= 14	FAN PRESSURE RATIO	= 1.386
BYPASS RATIO	= 0	BYPASS RATIO	= 6.1
TURBINE INLET TEMP	= 2000°F (1094°C)	TURBINE INLET TEMP	= 1400°F (760°C)

Figure 3.2-4

Propulsion System Sizing and Performance
4 Engine Configurations

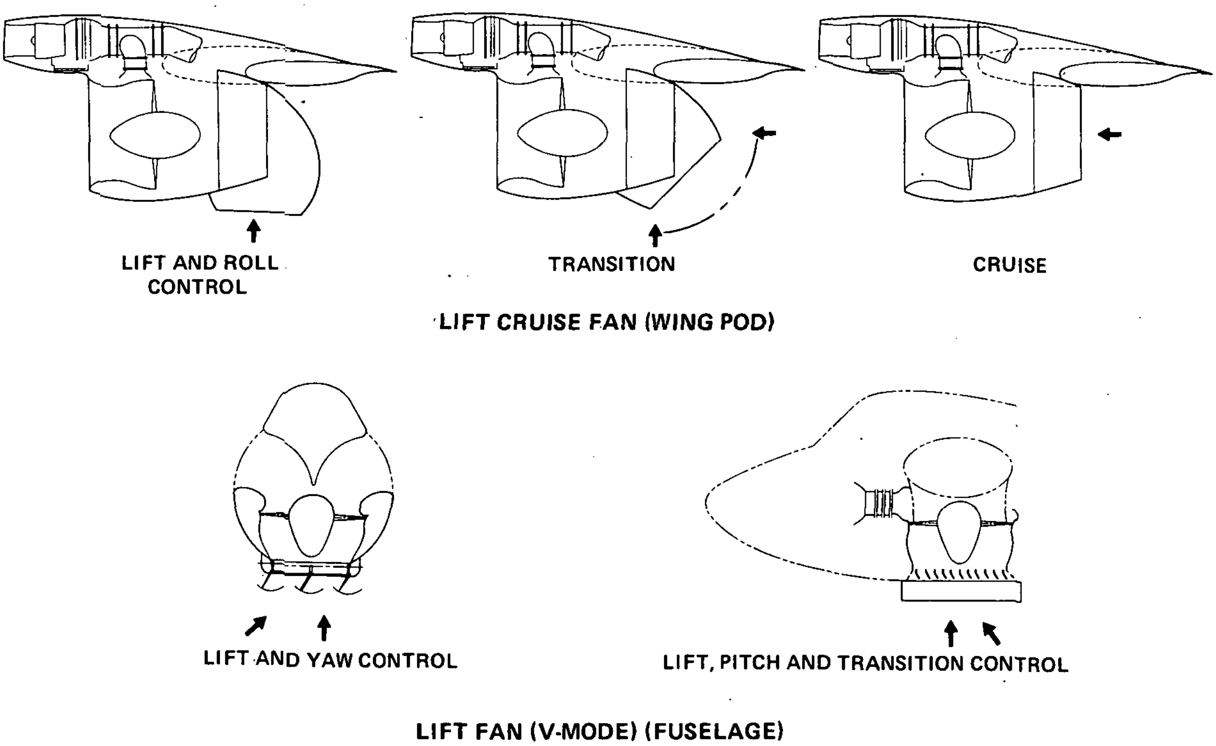
	VT107-4-4I		VT107-4-4J		VT107-4-4K	
GAS GENERATOR						
Thrust Scaling Factor	2.97		3.135		2.53	
Scaled Gas Flow Rate - lb/sec (kg/sec)	200	(90.7)	211	(95.7)	170.4	(77.3)
Compressor Face Dia - in (cm)	34.7	(88.1)	36.6	(90.4)	32.0	(81.3)
Gas Generator Length - in (cm)	83.0	(210.8)	85.0	(215.9)	77.0	(195.6)
FANS						
Design Pressure Ratio (100% N_f, SLS Uninstalled)	1.386		1.386		1.386	
Design Thrust Level Per Fan - lb (kg)	40,300	(18,300)	42,400	(19,200)	34,400	(15,600)
Fan Operating Pressure Ratio at Intermediate, 90°F	1.324		1.324		1.324	
Installed Thrust/Fan at Intermediate, 90°F - lb (kg)	33,825	(15,375)	35,750	(16,250)	28,800	(13,090)
Fan Tip Dia - in (cm)	97.9	(248.7)	100.5	(255.3)	90.4	(229.6)
DUCT DIAMETERS						
Gas Generator to Fan (M_{MAX} = 0.3) - in (cm)	29.2	(74.2)	30.0	(76.2)	27.0	(68.6)
Interconnect Duct (M_{MAX} = 0.4) - in (cm)	18.3	(46.5)	18.8	(47.8)	16.9	(42.9)
VTOL INSTALLED PERFORMANCE						
Maximum VTO Thrust (T/W = 1.197) - lb (kg)	135,300	(61,400)	143,000	(64,900)	115,200	(52,300)
Emergency VTO Thrust (T/W = 1.03) - lb (kg)	116,400	(52,800	122,500	(55,600	99,200	(45,000)

3.2.2 THRUST VECTORING SYSTEMS - The fuselage mounted fans utilize louvers arranged in the longitudinal and lateral directions for thrust vectoring, Figure 3.2-5. The lateral louvers vector the flow forward or aft during transition. The louvers are also actuated to a staggered position to spoil fan thrust during pitch control applications. The longitudinal or fore and aft vanes are differentially actuated to provide the required yaw moment in powered lift flight. After transition to conventional flight, the yaw vanes act as doors by rotating to the closed position to form a clean external aircraft mold line.

A lift/cruise nozzle vectors the thrust of the lift/cruise fans as shown in Figure 3.2-5. The segments extend to vector the flow to the 90° position for a vertical takeoff. The segments are further extended to provide reverse thrust. The segments are retracted gradually to the cruise position during a normal transition. Cruise exit area regulation is incorporated in the lift/cruise nozzle design to provide approximately 20% variation in cruise exit area. This feature is required to obtain maximum thrust and SFC performance throughout the flight envelope.

The lift/cruise nozzle is equipped with a controllable opening on the upper section of the nozzle to act as a thrust spoilage system during a roll control demand.

FIGURE 3.2-5
THRUST VECTORING COMPONENTS



3.3 AIRCRAFT CONTROL

Aircraft control during conventional flight is provided by aerodynamic control surfaces on the wing and tail of the aircraft. Spoilers provide roll control, while the elevator and rudder provide pitch and yaw control, respectively. In transition aircraft lift is provided by both the wings and direct thrust of the lift fans. The lift fans are installed away from the center of gravity so that differential modulation of fan thrust magnitude and changes of thrust direction produce pitching, rolling, and yawing moments on the aircraft. As speed decreases to zero, all lift is provided by the lift fans and aircraft control is provided by fan thrust modulation and vectoring only. Thrust modulation is accomplished by gas energy transfer between fans and controlled by the Energy Transfer and Control (ETaC) system described in Reference 1. Height control is provided by variation of the fuel flow to all engines simultaneously increasing or decreasing the total lift on the aircraft.

The techniques of aircraft control, the static and dynamic characteristics of the systems, and aircraft stability during the powered lift mode of flight are described in the following paragraphs.

3.3.1 CONTROL GUIDELINES - The major control guidelines (Figure 3.3-1) consist primarily of (1) attitude control requirements in terms of angular acceleration and angular displacement in one second, (2) height control requirement in terms of vertical acceleration, and (3) a control dynamic response requirement. Two levels of attitude, height, and response requirements are specified. The control power requirements for normal operation (Level 1) are generally higher than for emergency operation (Level 2) as shown in Figure 3.3-1. However, failure of a gas generator or fan results in the reduction of differential thrust modulation capability for height control. Therefore, the selected aircraft configuration was analyzed in detail to determine its compliance with the guidelines for both levels.

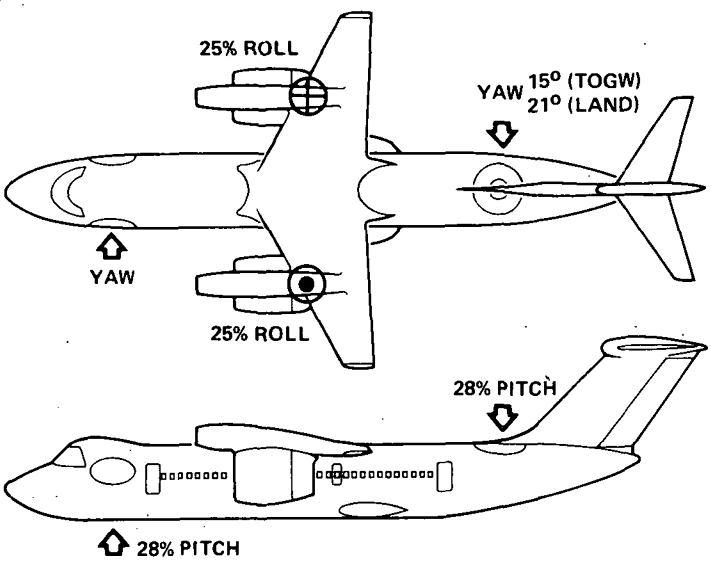
FIGURE 3.3-1
PRIMARY VTOL CONTROL GUIDELINES
CIVIL TRANSPORT CONCEPTS - SEA LEVEL 90°F

		LEVEL 1	LEVEL 2
ATTITUDE CONTROL			
ACCELERATION (RAD/SEC^2)	ROLL	±0.60	±0.30
	PITCH	±0.33	±0.20
	YAW	±0.25	±0.15
ANGLE IN 1 SEC (DEGREES)	ROLL	±10	±5
	PITCH	±6	±3
	YAW	±5	±2
COMBINED CONTROL		100% + 30% + 30%	
HEIGHT CONTROL			
WITH 50% ATTITUDE CONTROL (g)		±0.1	−0.1, +0.05
TRANSIENT RESPONSE (TIME CONSTANT)			
ATTITUDE CONTROL (SECONDS)		0.2	0.3
HEIGHT CONTROL (SECONDS)		0.3	0.5

3.3.2 SPECIFIC CONTROL REQUIREMENTS OF THE SELECTED AIRCRAFT - The basic requirements for control of the selected aircraft are shown fundamentally in Figure 3.3-2 in terms of percent thrust modulation for pitch and roll, and deflection angle in yaw. The transport pitch moment of inertia is nearly four times the roll moment of inertia. Consequently the thrust modulation requirement is higher for pitch than for roll even though the control guidelines specify a lower control power in pitch.

In the yaw axis the control requirement is satisfied by deflecting sideways the thrust of the fuselage mounted fans to produce a yaw moment couple. The thrust deflection angle needed is greatest at the minimum landing weight condition as indicated in Figure 3.3-2.

FIGURE 3.3-2
CONTROL REQUIREMENTS
VT107-4-4I

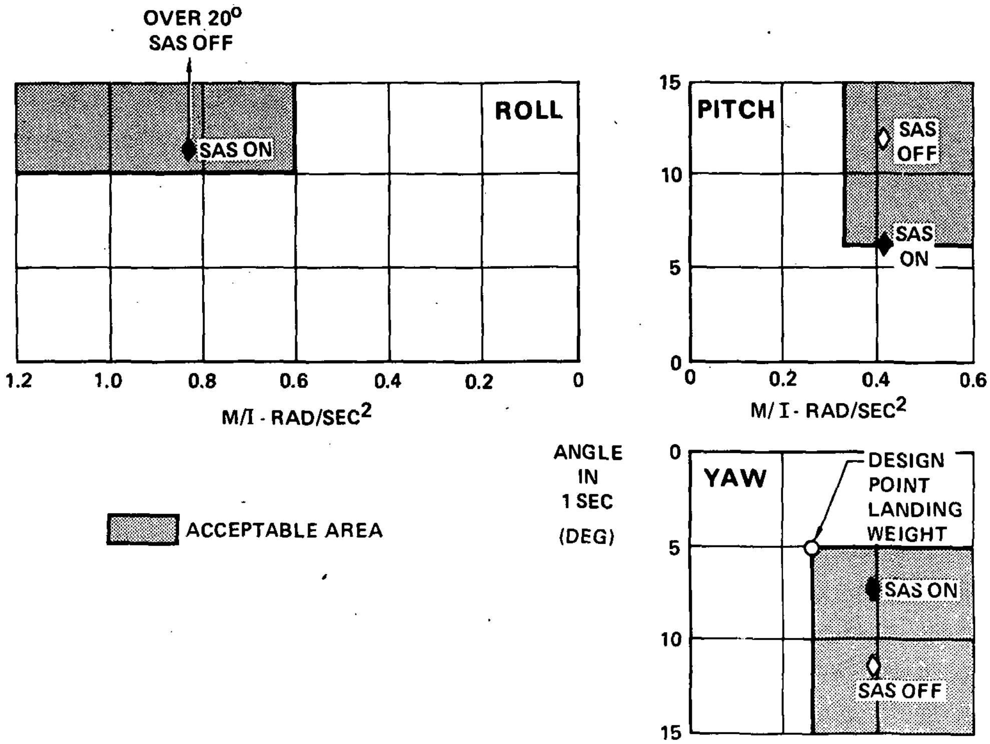


3.3.3 NORMAL ATTITUDE CONTROL - In the refinement of the selected configuration, the aircraft was analyzed for compliance with the study control guidelines. The results of this analysis are presented in Figure 3.3-3.

The propulsion system is sized according to the emergency (Level 2) requirements which are governing for the VT107-4-4I aircraft. Therefore, the gas generators and fans have thrust modulation capability in excess of the Level 1 acceleration (M/I) requirement in pitch and roll. The angle achieved in one second without stability augmentation easily satisfies the requirement, but the basic aircraft is unstable in hover. Therefore, the capabilities with a stability augmentation system were also evaluated. The stability augmentation system provides attitude stabilization which limits aircraft angular response. However, adequate capability is retained to show compliance with the study guide..nes.

Yaw control capability is designed by the guideline angular acceleration and displacement requirements at the minimum operating aircraft weight (indicated in Figure 3.3-3). The corresponding capabilities, therefore, at the takeoff weight condition are well in excess of the guideline minimums.

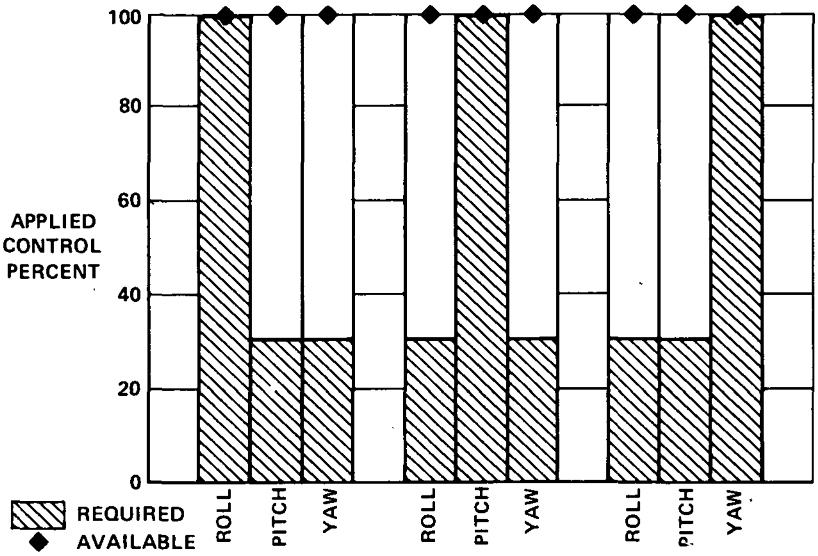
FIGURE 3.3-3
COMPLIANCE WITH LEVEL 1 CONTROL CRITERIA
VT107-4-4I
AT TOGW



The 4 engine configuration uses two independent pairs of interconnected fans and gas generators such that one pair is used for pitch and yaw control, and the other for roll. This arrangement permits application of 100% aircraft control in each axis simultaneously. As shown in Figure 3.3-4, only 100%-30%-30% combined control is required.

3.3.4 EMERGENCY ATTITUDE CONTROL - The direct effect of a gas generator or fan failure is an upsetting moment on the aircraft. An appropriate design through fan scroll splitting and emergency nozzles provides trim for the upsetting moment when the emergency system is activated without the need of pitch or roll control inputs. In an indirect way, however, the failure results in reduced control margins as the lift system is operated closer to its design limits in emergency. Following the failure, the thrust spoiling mechanization remains unaffected but the maximum thrust change capability through spoiling is altered in proportion to the change in total fan thrust. Therefore, some attitude control-lift coupling results for large attitude control inputs. The maximum coupling does not exceed 0.05 g (minimum height control capability in emergency) at the maximum vertical takeoff gross weight during full input of attitude control.

FIGURE 3.3-4
COMPLIANCE WITH COMBINED CONTROL REQUIREMENT
VT107-4-4I



The fan design thrust level is determined by adding the Level 2 thrust modulation requirement to the emergency (gas generator or fan out) thrust of the normally operating pair of interconnected fans. The condition which sizes the fan is then identified as failure of a fuselage mounted fan or gas generator at the takeoff gross weight combined with the Level 2 pitch control requirement. The control availabilities in roll and yaw are then well in excess of the criteria as shown in Figure 3.3-5.

3.3.5 HEIGHT CONTROL - Since the emergency T/W requirement of 1.03 sizes the gas generator, there is an extra margin of height control under normal operating conditions. The normal T/W capability is 1.197. The attitude control availabilities for a 0.197 g height control are shown in the Level 1 compliance part of Figure 3.3-6. At a height control of 0.1 g, which is the borderline of acceptability, shown in Figure 3.6-6, the pitch and roll attitude control availabilities would be significantly higher than at T/W 1.197. Yaw control availability would be slightly reduced at 0.1 g height control because the nominal thrust level is lower.

Failure of any gas generator or fan in the VT107-4-4I concept is about equally significant with respect to the requirement of height control plus 50% attitude control guideline, but affects the pitch axis most. The steady state and transient capabilities were extensively considered and evaluated to establish compliance with the guidelines as shown in Figure 3.3-6.

FIGURE 3.3-5
COMPLIANCE WITH LEVEL 2 CONTROL CRITERIA
VT107-4-4I
AT TOGW

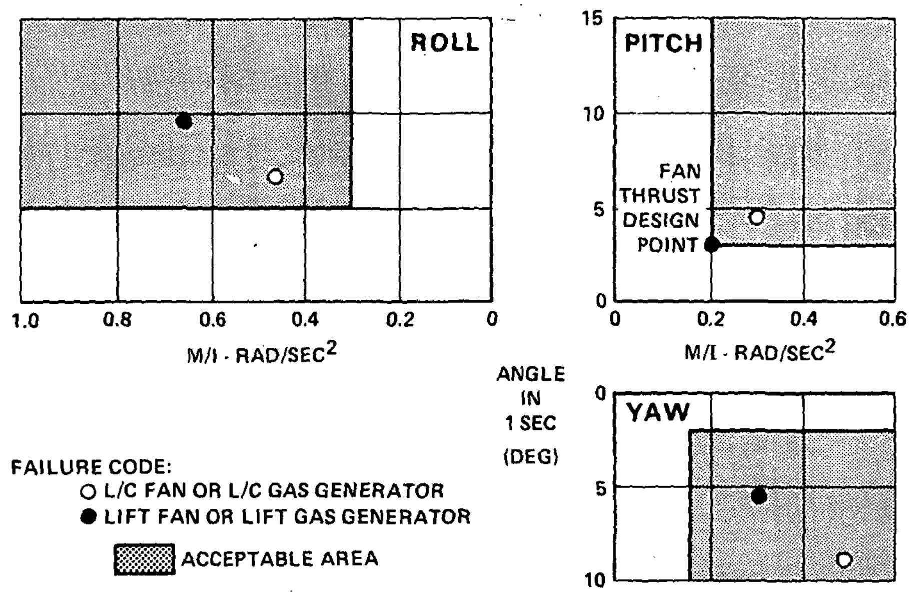
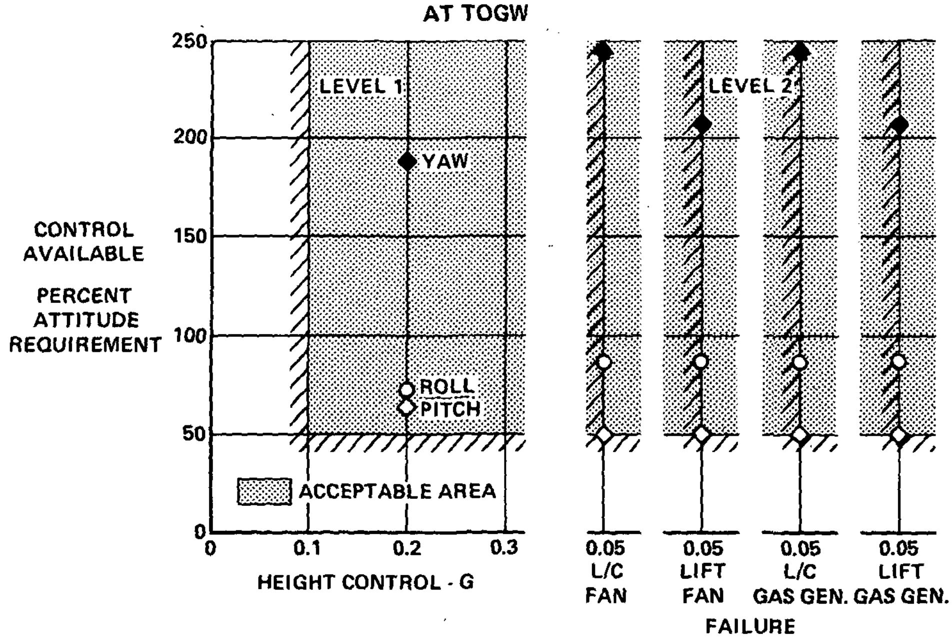


FIGURE 3.3-6
COMPLIANCE WITH HEIGHT CONTROL REQUIREMENT
VT107-4-4I
AT TOGW

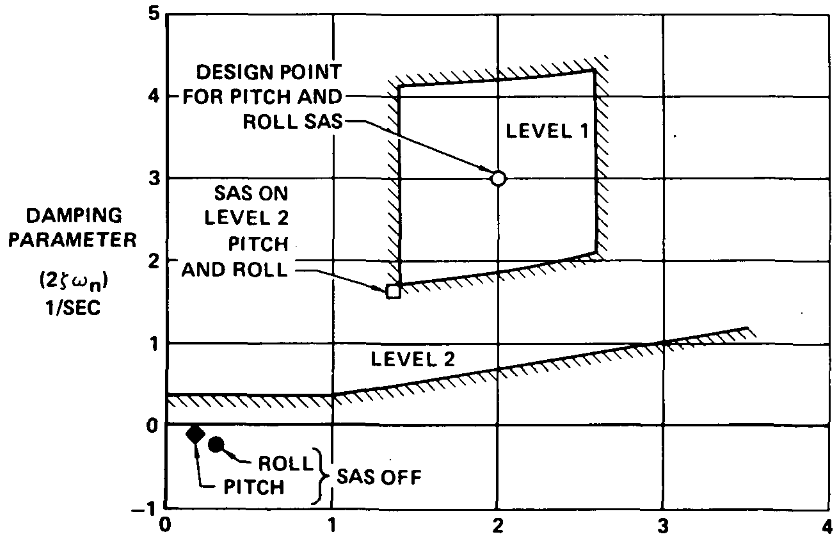


3.3.6 STABILITY CONSIDERATIONS - Within the scope of this study only the hover and low speed stability characteristics were evaluated. Typically, the basic (SAS OFF) stability characteristics of fixed wing VTOL aircraft are defined by a low frequency unstable oscillatory mode in pitch and roll as shown in Figure 3.3-7. In compliance with the guideline requirement, a SAS was selected which provides frequency and damping characteristics within the acceptability area for Level 1 as shown also in Figure 3.3-7. A root locus study was performed to establish SAS feedback gains which provide a natural frequency near the 2 radians/second and a damping parameter value near 3 seconds^{-1}. These SAS characteristics were used in the evaluation of the angle in one second capabilities for compliance with the Level 1 control requirements as shown in Figure 3.3-3.

Failure of a fan or gas generator results in reduction of the SAS forward loop gain such that frequency and damping are altered. The Level 2 natural frequency and damping fall therefore just outside the Level 1 area and well within the Level 2 area of acceptability as shown in Figure 3.3-7. These reduced damping and frequency values were then used in evaluating the angle achieved in one second to check compliance with the Level 2 control requirements as shown in Figure 3.3-5.

3.3.7 CONTROL SYSTEM REPONSE - Fan speed response varies directly with fan polar moment of inertia and inversely as the ratio of the accelerating torque to the corresponding speed change increment. Fan thrust response includes the effects of fan speed change, tip turbine thrust fraction, and the actuation lags. Control moment response consists of two components: (1) fan thrust response from the increase of gas energy, and (2) thrust spoilage response.

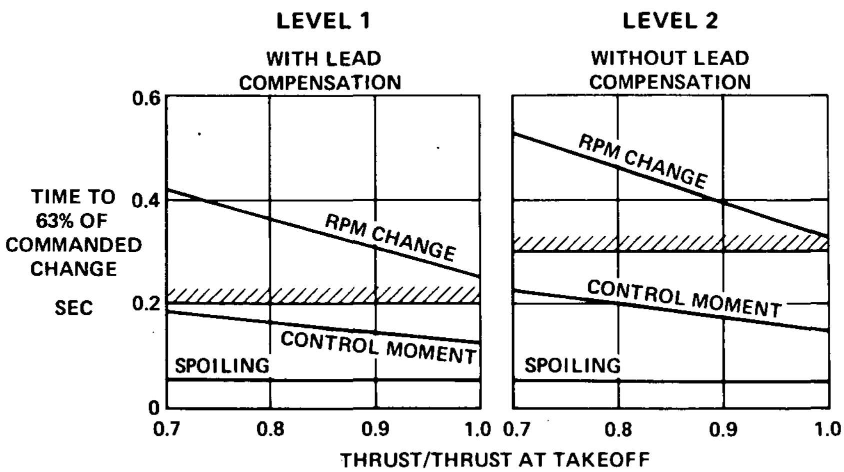
FIGURE 3.3-7
COMPLIANCE WITH STABILITY CRITERIA
VT107-4-4I



Lead compensation is used in the VT107-4-4I aircraft to provide good response which satisfies the 0.2 second control moment time constant criterion throughout the operating range of power settings at zero speed. As discussed previously, the propulsion system was sized by emergency requirements. The normal control thrust modulation capabilities are therefore in excess of the normal control requirement. The excess modulation margin is sufficient to permit effective use of lead compensation for response improvement. With lead compensation therefore, the control response is expected to meet the 0.2 second requirement as shown in Figure 3.3-8. In emergency (Level 2), however, no excess modulation of turbine power is available and lead compensation for large control inputs is not effective. The response characteristics are expected to be in excess of 0.2 second at the lower operating thrust levels but can still meet the emergency requirement of 0.3 second as shown in the right half of Figure 3.3-8.

Height control response was not specifically evaluated in this study. Because height control is provided by direct gas generator power modulation, the gas generator dynamic characteristics are directly involved. Although increasing fan thrust response depends mostly on fan speed change, which is slow, and only to a small degree on direct turbine thrust, the overall response is not necessarily slow. Past study experience shows that the gas generator can provide a lead compensating effect such that the overall response is faster than the response of the fans. Since gas generator dynamics cannot be adequately defined within the scope of this study, the assumption is made that height control response is adequate to meet the response guidelines.

FIGURE 3.3-8
COMPLIANCE WITH ATTITUDE CONTROL RESPONSE REQUIREMENT
VT107-4-4I



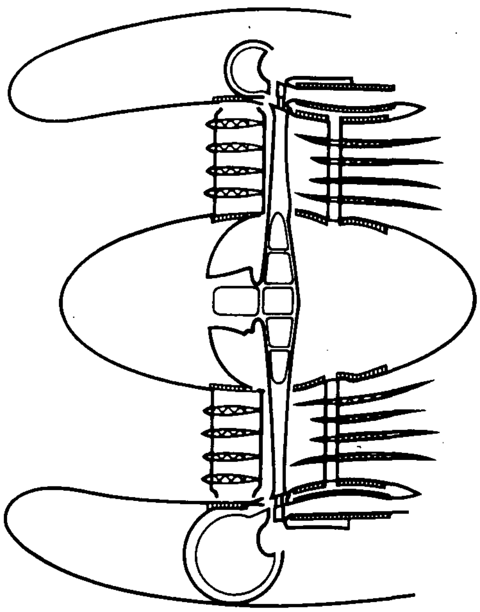
3.4 NOISE SIGNATURE

Two criteria were used as a measure of the acoustic performance of the VT107-4-4I aircraft; the area enclosed by the 95 PNdB contour and the maximum Perceived Noise Level (PNL) at 500 ft (150 m) sideline distance. While 95 PNdB maximum at 500 ft (150 m) sideline distance was a goal for this aircraft, sideline noise does not give a complete picture of an aircraft's acoustic characteristics. Ground noise contours and the area enclosed by the 95 PNdB contour are more significant. Parameters which influence the acoustic characteristics of the aircraft and which were investigated are the aircraft's gross weight, the takeoff profile, and the amount of acoustic treatment (suppression) applied to the engines.

The acoustic suppression selected for the lift/cruise fans in this study is shown in Figure 3.4-1. The exhaust suppressor consists of four acoustically treated rings. The duct walls and the center body walls in this region are also treated. This suppressor design produces an attenuation of approximately 9.5 PNdB for the fan exhaust acoustic source. The cruise fan inlet suppressor shown in Figure 3.4-1 consists of four treated rings and gives a reduction in PNL of approximately 7 PNdB. Since the lift fan inlets point in a vertical direction, there is no need in this design to use acoustic suppression for the lift fan inlet radiated noise. In this case the directivity is responsible for sufficiently reducing the PNL.

FIGURE 3.4-1
ACOUSTIC SUPPRESSION CONFIGURATIONS

LIFT/CRUISE FAN



GAS GENERATOR INLET

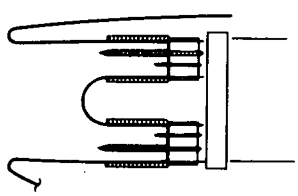


Figure 3.4-1 also shows the suppressor design for the gas generator inlets. Since all four of the gas generator inlets are in the horizontal plane, all of them will require suppression. The suppressor design shown here reduces the gas generator inlet PNL by 10 PNdB.

An important parameter in minimizing the noise for a V/STOL aircraft is the takeoff profile. Figure 3.4-2 is a plot of aircraft altitude as a function of aircraft range for the optimum takeoff profile determined during this study. Using this takeoff profile the ground noise contours shown in Figure 3.4-3 were computed. The results of these studies show that Model VT107-4-4I with the proposed acoustic suppression design will have a maximum sideline PNL of 98.8 PNdB at 500 ft (150 m). The 45 degree takeoff profile was selected based on considerations of noise, block time, and fuel consumption. For this profile the area enclosed by the 95 PNdB contour on takeoff will be approximately 44 acres (0.178 sq km).

Further reductions in the area enclosed by the 95 PNdB contour could be achieved by taking off at a steeper angle initially. For example Figure 3.4-4 shows the ground noise contours associated with a vertical climb (90 degrees). The area enclosed by the 95 PNdB is now approximately 34 acres (0.138 sq. km); however the sideline noise is still approximately the same as was determined in Figure 3.4-3.

The noise contours for the VT107-4-4J and VT107-4-4K aircraft are approximately the same as shown on Figure 3.4-3. Area enclosed by the 95 PNdB contours and 500 ft (150 m) sideline noise levels are as follows:

	VT107-4-4I M = 0.75	VT107-4-4J M = 0.85	VT107-4-4K 200 nm VTOL
95 PNdB - Acres (sq km)	44 (0.178)	45 (0.182)	41 (0.168)
500 Ft (150 m) Side line - PNdB	98.8	99.1	98.1

FIGURE 3.4-2
AIRCRAFT TAKEOFF PROFILE
T/W = 1.05 VT107-4-4I

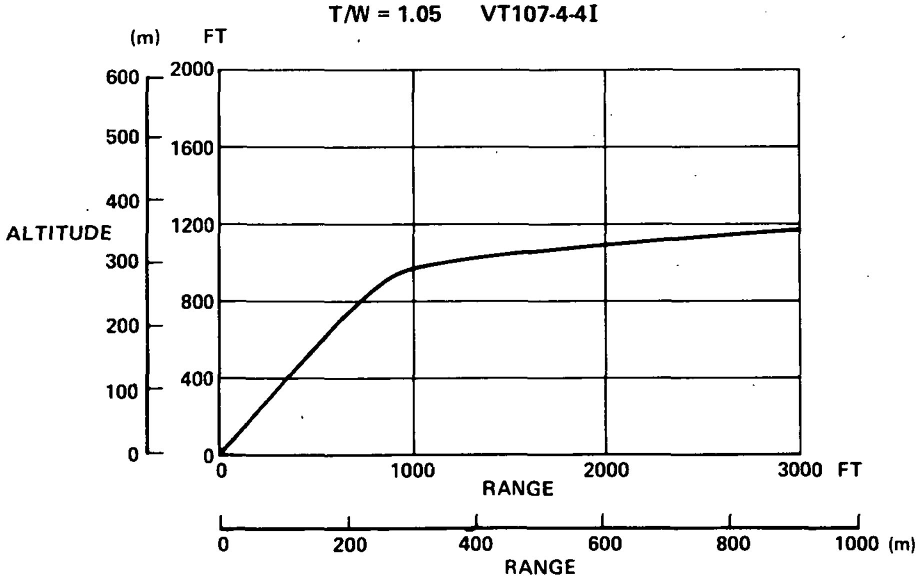


FIGURE 3.4-3
GROUND NOISE FOOTPRINT
T/W = 1.05 VT107-4-4I

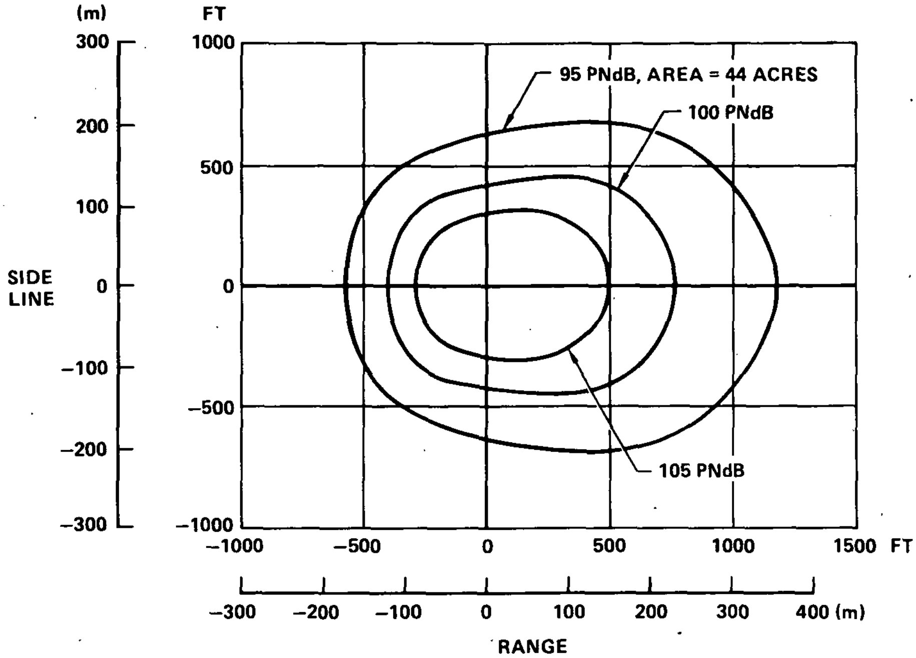
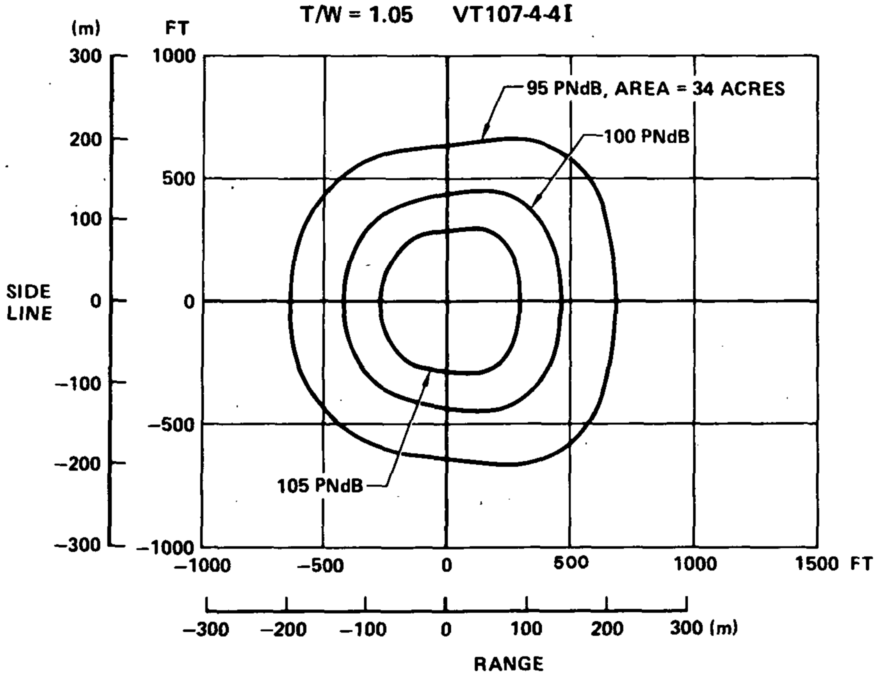


FIGURE 3.4-4
GROUND NOISE FOOTPRINT VERTICAL TAKEOFF
T/W = 1.05 VT107-4-4I



3.5 DIRECT OPERATING COST

This section presents the results of a Direct Operating Cost (DOC) analysis of the selected V/STOL aircraft. The method used to estimate DOCs is the 1968 AIA V/STOL Standard Method, Reference 4, modified by the 1973 guidelines outlined here and in Appendix A. Airframe is priced at \$90 and \$110 per pound (\$198 and \$242/kg). Engine prices are based on a 20,000 pound (9070 kg) thrust unit costing \$690,000. Of this engine price, 58% or \$400,000 is for remote lift fans, and 42% or \$290,000 is for gas generators. The effect of a ± 20% variation in engine prices is evaluated. Propulsion system costs are scaled according to Figure 3.5-1. which shows the trend of reduced price per unit of thrust as thrust increases. Deviating from the 1968 AIA Method, aircraft utilization was assumed to be either 2500 or 3500 hours per year. Other deviating factors and rates from the AIA Method are summarized in Figure 3.5-2. All calculated DOCs are in 1974 dollars. DOCs are calculated with the range of parameters indicated above to present the expected limits of the data.

Figure 3.5-3 summarizes the DOCs for the 4 engine aircraft, VT107-4-4I and VT107-4-4J, selected for Tasks 1A and 1B, respectively. DOC is presented in cents per available seat statute mile, as well as the cost relative to the VT107-4-4I aircraft DOC for the 200 nm (740 km) VTOL mission and the 800 nm (1480 km) STOL mission for 3500 hours yearly utilization.

FIGURE 3.5-1
PRICE SCALING FACTOR FOR PROPULSION SYSTEM, LIFT FANS, OR GAS GENERATOR

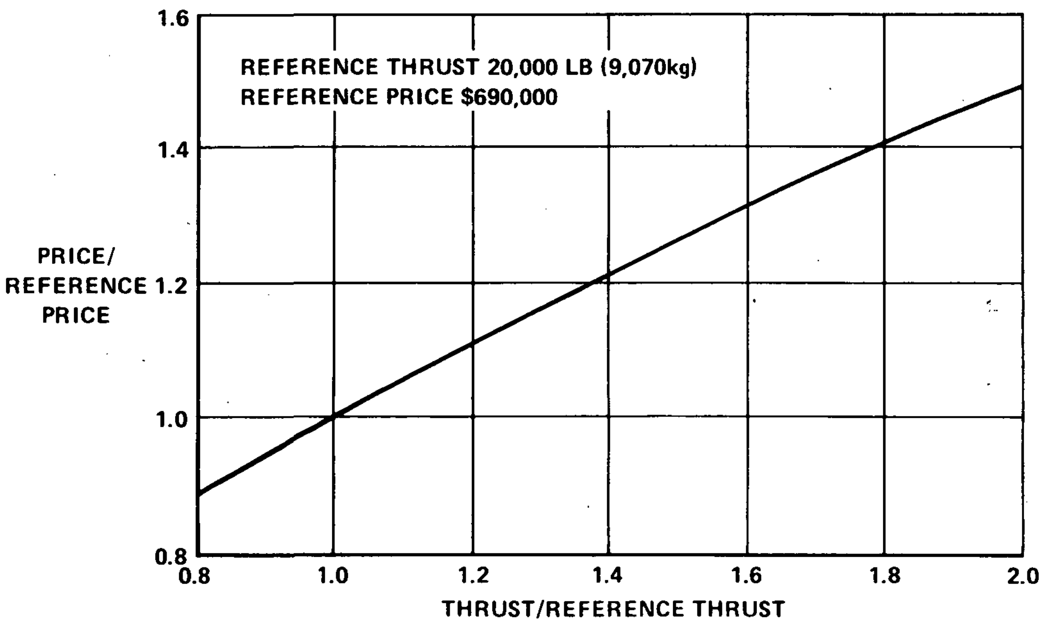


FIGURE 3.5-2
DIRECT OPERATING COST FACTORS

COST ITEM	STUDY GUIDELINES	1968 AIA METHOD
CREW COST ($/BLOCK HR)	0.067 [TOGW/1000]+134	42.8 + 0.1051 x V_{CRUISE}
FUEL		
KEROSENE	14 ¢/GAL. (3.70 ¢/ℓ)	10 ¢/GAL. (2.64 ¢/ℓ)
OIL	10 $/GAL. (2.64 $/ℓ)	7.5 $/GAL. (1.98 $/ℓ)
INSURANCE RATE	2%	3%
MAINTENANCE		
CRUISE ENGINE (LABOR & MATL)	0.65 AIA	AIA
LIFT ENGINE (LABOR & MATL)	0.50 AIA	AIA
BURDEN	1.50 DIRECT MAINT LABOR	0.60 TOTAL DIRECT MAINT
SPARES		
AIRFRAME	10%	8%
CRUISE ENGINE	25%	40%
LIFT ENGINE	20%	–
UTILIZATION (HR/YR)	2500 & 3500	FUNCTION OF BLOCK TIME

FIGURE 3.5-3
DIRECT OPERATING COST SUMMARY
TASK 1 SELECTED AIRCRAFT
1974 DOLLARS, 1968 AIA METHOD
UTILIZATION: 3500 HR/YR

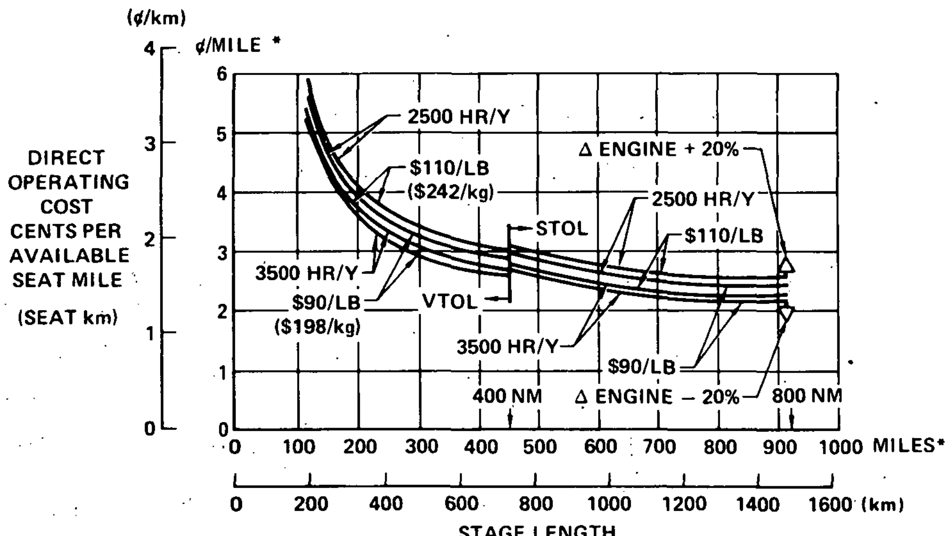
AIRCRAFT MODEL	400 NM VTOL MISSION 460 STATUTE MILES OR 740 km				800 NM STOL MISSION 920 STATUTE MILES OR 1480 km			
	AIRFRAME COST				AIRFRAME COST			
	$90/LB ($198/kg)		$110/LB ($242/kg)		$90/LB ($198/kg)		$110/LB ($242/kg)	
	DIRECT OPERATING COST				DIRECT OPERATING COST			
	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE
BASELINE AIRCRAFT VT107-4-4I	2.573 (1.599)	1.0	2.680 (1.665)	1.0	2.138 (1.328)	1.0	2.231 (1.386)	1.0
VT107-4-4I + 20% Δ ENGINE COST	2.686 (1.669)	1.044	2.793 (1.735)	1.042	2.231 (1.386)	1.043	2.324 (1.444)	1.042
VT107-4-4I −20% ΔENGINE COST	2.459 (1.528)	0.956	2.566 (1.594)	0.957	2.045 (1.271)	0.957	2.138 (1.328)	0.958
VT107-4-4J M = 0.85	2.613 (1.623)	1.016	2.717 (1.688)	1.014	2.157 (1.340)	1.009	2.246 (1.396)	1.007

The Task 1A aircraft cruises at 0.75 Mach and the Task 1B aircraft cruises at 0.85 Mach. Slightly higher DOCs are incurred for the Task 1B aircraft although some advantages in lowered block time results as indicated in Section 2.3 for both the 400 nm (740 km) and 800 nm (1480 km) missions.

To indicate the sensitivity to engine costs, DOCs for the VT107-4-4I aircraft are also shown for ± 20% incremental engine costs. This results in ± 5% DOC variation. Since DOC of the 4 engine and 6 engine aircraft and the DOC for the 0.75 M and 0.85 M cruise aircraft are for all practical purposes equal, it is concluded that parameters other than DOC must critically impact the selection of aircraft configuration to satisfy the short haul market.

3.5.1 DOC VERSUS STAGE LENGTH - Figure 3.5-4 shows the band of DOCs as a function of stage length. The discontinuity in the curves at 400 nm (740 km) is due to different flight profiles resulting in reduced fixed time for the VTOL missions. All DOC s under 400 nm (740 km) are based on the VTOL mission rules, those over 400 nm (740 km) on the STOL mission rules.

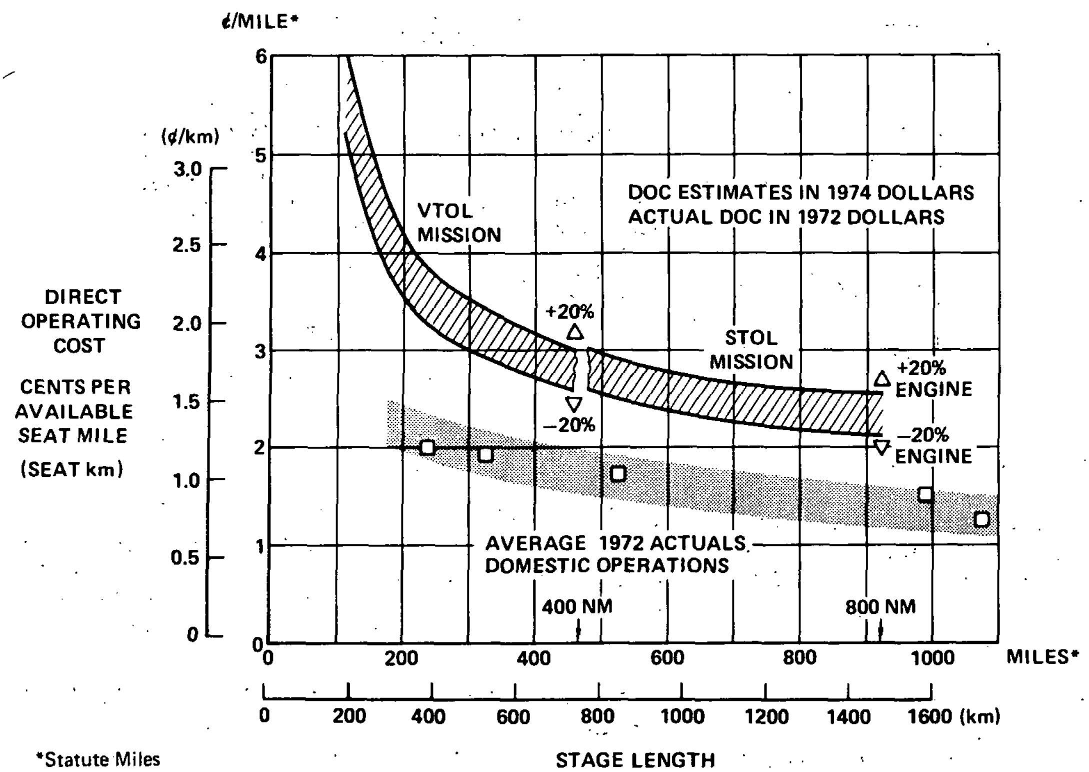
FIGURE 3.5-4
DIRECT OPERATING COST
VT107-4-4I, 1974 DOLLARS, 1968 AIA METHOD



*Statute Mile

Figure 3.5-5 compares actual DOCs for conventional transports in domestic service with the calculated DOCs for the baseline V/STOL aircraft. The actual CTOL DOCs are taken from Reference 4. They are averages for turbo-fan-powered powered aircraft in 1972 domestic operations. DOCs are presented in cents per available seat mile (statute mile). The actual CTOL DOC data are some 20 to 40% lower than the estimated DOCs for the lift fan V/STOL transport. However, this direct comparison has to be placed in the proper context. First, CTOL DOCs are in actual dollars for the year 1972 and the estimated V/STOL DOCs are in 1974 dollars. In addition, factors other than DOC should be considered when comparing the economics of V/STOL aircraft with CTOL aircraft. When total door-to-door economics and convenience factors for the passenger are considered it appears possible that a fare structure acceptable to the passenger and providing a return on investment for the airline could make the V/STOL aircraft an economically viable system competitive with CTOLs. It was not the purpose of this study to prove this point.

FIGURE 3.5-5
DIRECT OPERATING COST COMPARISON
VT107-4-4I AND ACTUAL DOC



3.5.2 TASK 2 - SELECTED AIRCRAFT DOC - The DOC for the 4 engine VT1074-4K aircraft selected for Task 2A is presented in Figure 3.5-6. The Task 2A mission is a 200 nm (370 km) mission with the cruise speed of 0.75 M.

As indicated in Section 2.4, the 4 engine VT1074-4K aircraft would change only slightly if designed for 0.65 M cruise to satisfy the Task 2B mission. Consequently, there appears to be no economic advantage to a 0.65 M cruise aircraft for the 200 nm (370 km) mission.

A comparison of the VT107-4-4I aircraft at a 200 nm (370 km) stage length with the VT107-4-4K aircraft indicates an increase of only 3% in DOC. The versatility of mission capability up to 800 nm (1480 km) is available in the VT107-4-4I for the tradeoff of 3% increased DOC in the 200 nm (370 km) mission and approximately 9% increased initial investment.

FIGURE 3.5-6
DIRECT OPERATING COST SUMMARY
TASK 2 SELECTED AIRCRAFT
1974 DOLLARS, 1968 AIA METHOD

AIRCRAFT MODEL	200 NM VTOL MISSION (230 STATUTE MILES OR 370 km)				
	UTILIZATION (HR/YR)	AIRFRAME COST $90/LB ($198/kg)		AIRFRAME COST ($110/LB ($242/kg)	
		DOC ¢/SEAT MILE (¢/SEAT km)	RELATIVE DOC	DOC ¢/SEAT MILE (¢/SEAT km)	RELATIVE DOC
VT107-4-4K	2500	3.544 (2.202)	1.0	3.705 (2.302)	1.0
VT107-4-4K	3500	3.233 (2.009)	0.91	3.358 (2.086)	0.91

3.6 DISPATCH RELIABILITY

System simplicity, emphasizing the reduction of dynamic components, is the major factor contributing to an optimum propulsion system dispatch reliability. This optimum is achieved for a 100 passenger VTOL transport in the VT107-4-4I configuration by minimizing gas generators and fans; interconnect ducting is utilized only for control and gas generator or fan out during the short powered-lift time interval.

Only two short-coupled engine/fans are operated during cruise which constitutes 90% of the mission time. For this reason, the dispatch reliability of the VT107-4-4I aircraft is expected to exceed that of a conventional 4 engine aircraft.

An extended discussion of the favorable impact of reduced number of engines per aircraft on dispatch reliability of the aircraft is presented in Section 6 of Reference 1. Also discussed in the same section is the effect of poor dispatch reliability on airline operation and economics.

3.7 WEIGHTS

Weight Evaluation Techniques - The evaluation techniques which were applied to the subject aircraft were developed by MCAIR and are considered fully applicable to the aircraft types and sizes that were studied.

Several approaches are combined to form the overall weight appraisal system. They include:

(a) Statistical Correlations - Weight equations derived by correlating design parameters to actual weights are utilized for predicting a large percentage of the vehicle weight. Basically, the procedure considers the shell structure required for local airloads and then adds weight for various design complexities and functions which are incorporated into the design. This method applies most directly to the individual structural groups.

(b) Layout Analyses - Several areas of the aircraft investigated required that layout analyses be performed.

(c) Vendor Supplied Weights - The weights of gas generators and remote fans have been derived from data of Reference 5.

Group Weight Statement - Figure 3.7-1 provides the estimated group weights for the selected point design configurations. It includes:

(a) VT107-4-4I (TOGW = 113,000 lb) (51,250 kg)

(b) VT107-4-4J (TOGW = 119,000 lb) (53,700 kg)

(c) VT107-4-4K (TOGW = 96,400 lb) (43,720 kg)

Discussion of Group Weight Derivations - The selected configurations presented in the Group Weight Statement are the results of extensive parametric studies used to aid in arriving at a vehicle capable of performing the guideline VTOL mission. As these aircraft are evaluated as 1985 production vehicles, structural and subsystem group weights were reduced assuming the use of advanced materials and fabrication techniques as well as the use of advanced state-of-the-art subsystem components. All structural group weights have had a weight correction factor (WCF) of 75% applied. This assumes a 25% reduction in structural weight through use of advanced materials and manufacturing techniques and a 10% reduction for subsystems. These represent weight savings over current CTOL transports.

Figure 3.7-1

Group Weight Breakdown VT107-4-4I Series

ITEM	TASK 1 M = 0.75 VT107-4-4I lb	kg	TASK 1 M = 0.85 VT107-4-4J lb	kg	TASK 2 200 NM VT107-4-4K lb	kg
Wing	6420	2911	7430	3369	5340	2421
Vertical Tail	1780	807	1900	861	1480	671
Horizontal Tail	1165	528	1235	560	970	439
Fuselage	13353	6055	13971	6336	12709	5763
Landing Gear	3140	1424	3305	1498	2680	1215
Surface Controls	1220	553	1280	580	1150	521
Engine Section	520	235	542	245	500	226
Nacelles	2260	1024	2340	1061	2100	952
Propulsion						
Gas Generators	6660	3020	7120	3229	5460	2476
Air Induction	616	279	648	293	524	237
Fuel System	690	312	710	322	590	267
Controls	545	246	545	246	545	246
Lift Fan & Louvers	6450	2935	6772	3071	5176	2347
L/C Fans & Deflectors	8380	3800	8760	3972	6955	3154
Ducting & Valves	5580	2530	5850	2653	4800	2176
Start	180	81	180	81	180	81
APU	711	322	711	322	711	322
Instruments	606	274	606	274	606	274
Hydraulics	715	324	715	324	715	324
Electrical	1430	648	1430	648	1430	648
Electronics	859	389	859	389	859	389
Furnishings	6300	2857	6300	2857	6300	2857
Air Conditioning	1750	793	1750	793	1750	793
Auxiliary Gear	40	18	40	18	40	18
Weight Empty	71370	32367	74999	34013	63570	28830
Crew & Misc.	1430	648	1430	648	1430	648
Operating Weight Empty	72800	33015	76429	34661	65000	29478
Payload	20000	9070	20000	9070	18000	8163
Fuel						
200 nm (370 km)	-	-	-	-	13400	6077
400 nm (740 km)	20200	9161	22571	10236	-	-
800 nm (1480 km)	32593	14781	36971	16767	-	-
VTOGW	113000	51247	119000	53968	96400	43718
STOGW	125400	56870	133400	60498	-	-

4. CONCLUSIONS

The major characteristics of the civil aircraft selected in Tasks 1 and 2 are summarized in Figure 4-1.

FIGURE 4-1
CIVIL AIRCRAFT COMPARISON

		VT107-4-4I	VT107-4-4J	VT107-4-4K	
		TASK 1A	TASK 1B	TASK 2A	TASK 2B
CRUISE MACH NO. (GUIDELINES)		0.75	0.85	0.75	0.65 NO BENEFIT
VTOGW	LB (kg)	113,000 (51,250)	119,000 (53,970)	96,400 (43,720)	
STOGW	LB (kg)	125,400 (56,870)	133,400 (60,500)	–	
UNIT FLYAWAY COST RATIO		1.00	1.04	0.92	
DOC CENTS PER SEAT STAT MILE (CENTS PER SEAT km)					
200 NM (370 km)		3.32 (2.06)	–	3.23 (2.01)	
400 NM (741 km)		2.57 (1.60)	2.61 (1.62)	–	
800 NM (1480 km)		2.14 (1.33)	2.16 (1.34)	–	
95 PNdB - ACRES (SQ km)		44 (0.178)	45 (0.182)	41 (0.166)	

Note: DOC Based on \$90/lb (\$198/kg) Airframe Cost and 3500 hrs Annual Utilization

The 4 engine aircraft selected for Task 1 is considered to be a more acceptable aircraft to airline customers than the 6 engine aircraft configuration selected in the 1972 study reported in Reference 1. The selected aircraft price is 5% less even though the gross weight is 5% greater. The propulsion system price is less even though the propulsion system weight is greater. DOC is essentially equal. Airline investment is reduced.

The overall operational suitability of the 4 engine aircraft has been enhanced over the 6 engine aircraft selected in the 1972 study. The performance has been improved with only a slight weight increase. The propulsion and control systems have been simplified, thus contributing to improved dispatch reliability, maintenance, maintainability, and safety. Precise control capability and flying qualities have been retained.

The DOC for an aircraft designed to cruise at M = 0.85 is the same as that of the basic aircraft designed to cruise at M = 0.75. Gross weight and aircraft price of the 0.85 M aircraft are increased 5% and 4% respectively. The only advantage for this aircraft is a slight decrease in mission block time.

A 4 engine aircraft designed to satisfy the 200 nm (370 km) mission of Task 2 and cruising at M = 0.75 is superior to a 6 engine aircraft designed for the same mission but designed to cruise at M = 0.65. Aircraft price is less by 4%. DOC is essentially equal. A 4 engine aircraft designed to cruise at M = 0.65 would be essentially the same as the M = 0.75 cruise aircraft.

The 4 engine aircraft designed for the 800 nm (1480 km) mission performs the 200 nm (370 km) mission at a DOC increase of 3% with an initial investment price increase of 9% compared to the aircraft designed for the 200 nm (370 km) mission. This may be a reasonable tradeoff for the added versatitility.

The lift/cruise fan transport aircraft is a viable aircraft concept to integrate into a civil short haul system. To further this conclusion, the system concept must consider the total door-to-door economics and convenience factors for the traveler in order to establish a fare structure permitting a satisfactory return on investment (ROI) for the airline.

5. LIST OF REFERENCES

1. Conceptual Design of a V/STOL Lift Fan Commercial Short Haul Transport; NASA CR-2184, January 1973.

2. Lift Fan V/STOL Transport Flight Control System Development Continuation: Total System Simulation Experiment; NASA CR-114683

3. Standard Method of Estimating Comparative Direct Operating Costs of Turbine Powered VTOL Transport Aircraft; Aerospace Industries Associated of America, Inc. (AIA), November 1968.

4. CAB Operating Cost and Performance Report; Volume VII, July 1973.

5. Remote Lift Fan Study Program; NASA CR-120972, August 1972.

APPENDIX A - DESIGN CRITERIA

The design criteria, mission requirements and guidelines which served as a basis for this study included the following major considerations:

(1) Flight safety and operating criteria

(2) Performance

(3) Noise levels

(4) General design guidelines

(5) Passenger comfort criteria and guidelines

(6) Economics

Recommendations resulting from the 1972 study (Reference 1) regarding the mission and guideline changes have been incorporated in the guidelines and statement of work for the current study. In addition, other guideline changes proposed by MCAIR or specified by NASA, which tend to minimize aircraft size and/or complication have been incroporated for the current study. A comparison of major guideline changes and the impact on design are discussed in this section.

MISSIONS

The major mission requirements dictating the size of the aircraft include; payload of 100 passengers, 0.75 M cruise speed, stage length of 400 nm (740 km) VTOL, and stage length of 800 nm (1480 km) STOL. The design point for the 1972 study (Reference 1) was the 400 nm (740 km) VTO mission. The impact on aircraft size for an 800 nm (1480 km) STOL mission was evaluated but was not a design requirement for the 1972 study. A second difference in the current study relates to the evaluation of the effect of a Mach 0.85 cruise requirement on the selected configuration. A comparison of the differences between the mission requirements for the 1972 and the current civil study are shown in Figure A-1. The additional tasks specified for the civil portion of the study are also included.

The Task 1B study goal is to establish the impact on aircraft design of a higher 0.85 Mach number cruise condition using the 400 nm (740 km) VTOL/800 nm (1480 km) STOL mission requirements. The Task 2A study goal is to establish a suitable aircraft design sized to match a pure VTOL mission with a stage length of 200 nm (370 km) and a cruise Mach number of 0.75. The flight safety level in Task 2A is reduced to gas generator out capability. Fan failures are not considered as the fans are designed for safe life as opposed to the fail safe system requirement of Task 1. The design sensitivity for a cruise speed of 0.65 M is to be evaluated in Task 2B.

Figure A-1

Mission Requirements

	1973 STUDY	1972 STUDY
TASK 1		
(A) Number Passengers (at 200 lb) (90.78 kg)	100	100
Range in Nautical Miles (km)		
STO	800 (1480) (Design)	800 (1480) (Effect on Design)
VTO	400 (740) (Design)	400 (740) (Design)
V_{CRUISE} - Mach Number	0.75	0.75
Flight Safety Capability	Fan or Gas Generator Failed	Same
(B) Same as Task 1A Except for Effect of Higher Cruise Speed		
V_{CRUISE} - Mach Number	0.85	--
TASK 2		
(A) Number Passengers (at 180 lb) (81.5 kg)	100	--
Range in Nautical Miles (VTO) (km)	200 (370)	--
V_{CRUISE} - Mach Number	0.75	--
Flight Safety	Gas Generator Failure	--
(B) Same as Task 2A Except for Effect of Lower Cruise Speed		
V_{CRUISE} - Mach Number	0.65	--

MAJOR GUIDELINES

Guideline requirements which have a major impact on the design are summarized in Figure A-2. The 1972 study guidelines are included for comparison.

Generally the refinement of the control requirements for specific flight conditions for the current study tends to reduce the propulsion system size and consequently aircraft gross weight. The fan pressure ratio is optional which permits better aircraft size optimization. Use of 25% composite structure weight reduction rather than the 40% value used in the 1972 study increases aircraft gross weight. Economics for the current study are based on 1974 dollars rather than 1971 dollars.

Figure A-3 summarizes the major differences between the aircraft resulting from the 1972 and the current study criteria outlined in Figures A-1 and A-2. The 1973 study results include both the 4 and 6 engine V/STOL designs. The offsetting effects of the guideline changes are evident in the similarity of gross weights for the 6 engine 1973 and 1972 V/STOL designs. Figure A-4 shows the 1973 study results superimposed on a plot of gross weight versus number of engines generated in the earlier study. (Figure 3-12 of Reference 1). As indicated in Figure A-4 the combined effect of guideline and mission changes is to reduce the gross weights of the 1973 study aircraft with respect to the 1972 study aircraft.

As shown in Figure A-3 the impact of the guideline changes on DOC is quite substantial, with the 1973 estimates increased approximately 15 percent. This reflects the effects of aircraft configurations and weight changes resulting from the guideline changes as well as the changes in parameter values specified in the guidelines for calculating DOC, including 1974 vs 1971 dollars.

Figure A-2
Major Guideline Requirements

	1973 STUDY	1972 STUDY
LIFT & CONTROL		
Attitude Control Power		
Level 1 (all engines)		
T/W	1.0	1.0
Roll, Pitch & Yaw Control	The significant requirements are the same	
Combined Control	100%, 30%, 30%	100%, 50%, 50%
Level 2 (engine out)		
T/W	1.0	1.0
Roll, Pitch & Yaw Control	Approximately 50% of Level 1	
Combined Control	100%, 30%, 30%	100%, 50%, 50%
Flight Path Control, VTOL		
Level 1		
T/W	1.0	1.0
Height Control	± .10g	± .10g
Attitude Control	50% of Level 1	100% of Level 1
Level 2		
T/W	1.0	1.0
Height Control	+ .05g, -.10g	+ .05g, - .10g
Attitude Control	50% of Level 2	100% of Level 2
Steady State T/W Without Attitude Control		
Level 1	1.05	---
Level 2	1.03	---
PROPULSION SYSTEM		
System Type	RLF	RLF, ILF
Performance Data Source	Optional	NASA/GE
Design Fan Pressure Ratio	Optional	1.25
AIRFRAME		
Structural Weight Reduction (with Composites) (%)	25	Optional (40 Used)
NOISE		
Noise Goal at 500 ft (150m) Sideline	95 PNdB	95 PNdB
ECONOMICS		
Direct Operating Cost	1974 Dollars	1971 Dollars
Airframe	\$90 & \$110/lb	Optional (\$100 lb /used)
Engine Cost		
Base Unit 20,000 lb Thrust	\$690,000	Varies with Buy Size
Fan	\$400,000	\$470,000*
Gas Generator	\$290,000	\$335,000*

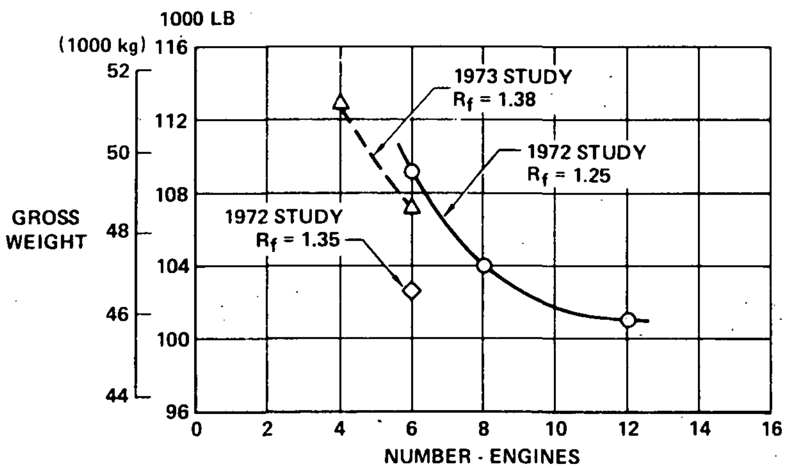
*Based on 2000 Units

FIGURE A-3
IMPACT OF GUIDELINE CHANGES
1972 vs 1973

		1973 STUDY		1972 STUDY
		4 ENGINE VT107-4-4I	6 ENGINE VT102-6-6C	6 ENGINE VT102-6-6A
VTOGW 400 NM (740 km)	(LB)	113,000	107,500	110,800 [1]
	(kg)	(51,250)	(48,750)	(50,300)
STOGW 800 NM (1480 km)	(LB)	125,400	121,000	121,300
	(kg)	(56,870)	(54,880)	(55,000)
FAN PRESSURE RATIO (DESIGN)		1.39	1.37	1.25
PERCENT MODULATION FOR CONTROL		28	23	23
AVERAGE DIRECT OPERATING COST RATIO		(NOTE 2)	(NOTE 2)	(NOTE 3)
400 NM (740 km)		1.00	1.01	0.85
800 NM (1480 km)		1.00	1.00	0.82
95 PNdB - ACRES [4]		44	43	50

Notes:
(1) VTOGW for "Basic" Mission of 400 NM (740 km) is 109,000 (49,400 kg)
(2) 1974 Dollars
(3) 1971 Dollars
(4) See Section 3.4 for Updated Noise Evaluation Methods

FIGURE A-4
STUDY RESULTS
1972 vs 1973

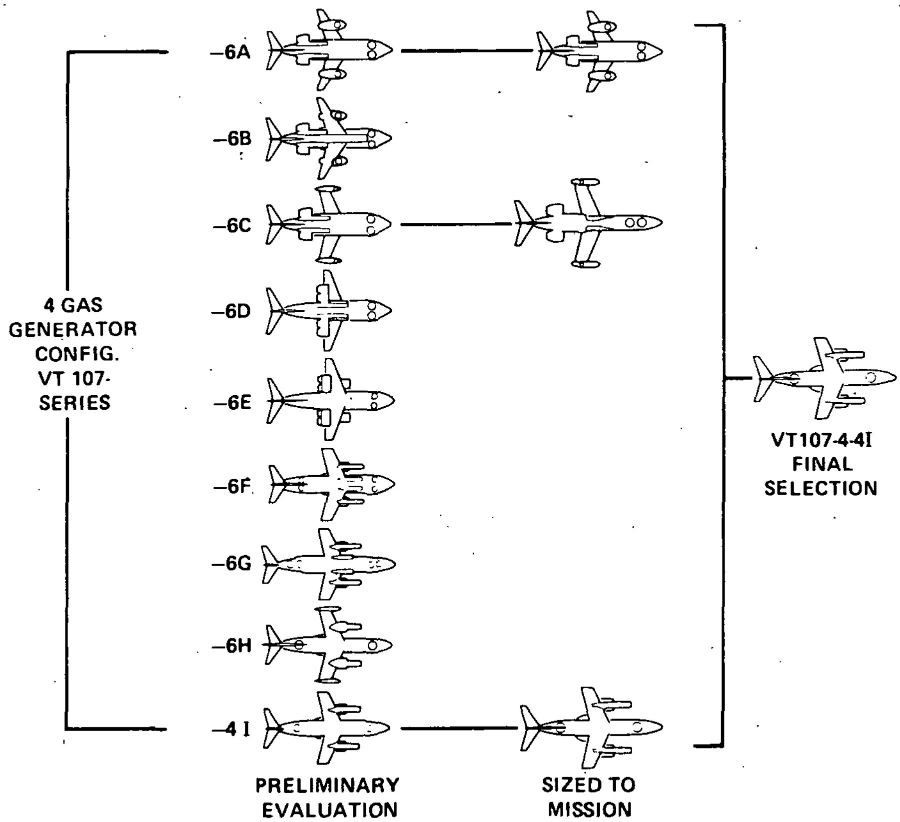


APPENDIX B - CANDIDATE 4 ENGINE AIRCRAFT EVALUATION

Nine different configurations were chosen to facilitate selection of the best 4 engine design. Figure B-1 shows the reduction to three aircraft and finally the selection of the VT107-4-4I configuration. Qualitative and quantitative design considerations and evaluation parameters governing the designs and selection were:

- Low noise level
- Low cost
- High reliability
- Effectiveness and simplicity of propulsion, lift, and control systems
- Utility and customer acceptance
- Good flight and operational characteristics in terminal environment and in cruise mode

FIGURE B-1
4-ENGINE CANDIDATE AIRCRAFT - CIVIL



A list of parameters used in the qualitative analysis with a discussion of the considerations entering the evaluation follows:

- Control - Roll, Pitch, Yaw - (% Modulation) - The required thrust modulation is computed based on vehicle inertias, engine locations, and guideline acceleration requirements. The resulting modulation thrust increments are rated with respect to the available thrust modulation capabilities. Configurations with thrust modulation increments requiring gas generator or fan oversizing receive the lowest ratings.

- Simple Flight Control System - The flight control systems are rated on number and complexity of components needed to perform the required control functions. Systems which are least complex and require the smallest number of components receive the highest ratings.

- Simple Control - Gas Generator or Fan Out - The gas generator or fan out control task is rated similarly to the basic control functions. Configurations requiring the smallest number and least complex additional components to be used in the event of gas generator or fan failure receive highest ratings.

- Gross Thrust Vectoring Range and Method - The best rated configurations are those where thrust vectoring can be performed with minimum additional complexity, least interference with other control functions, and with the smallest power penalty.

- Aerodynamic/Propulsion Interference Effects - The effects of engine and nacelle size and location on flowfields about the aircraft are considered. Wing tip pods may be designed to act as wing tip end plates, whereas wing pods located at mid-span create high drag and reduce lift. Large nacelles on the aft fuselage may necessitate larger horizontal tail exposed spans outboard of the nacelles for stability. Fan and engine inlet locations with low flow direction are desirable.

- CL_{max} (Flap Affected Area) - A wing without wing pods provides the largest flap span. Flap span deteriorates progressively as more or bigger pods are added to the wing.

- Ground Effects - The presence of a single jet efflux near the ground causes the air to be entrained around the lower surfaces of a vehicle, inducing a download on the vehicle. Fountain effects may also occur between multiple jets. The fountain and entrainment effects result in either a negative or positive ground effect depending on the distribution of engines and the height of the exhaust above the ground. Engines located close to the ground are downgraded because of reingestion and suck-down effects. Jet exhaust canted a few degrees outboard is usually favored because of reduced reingestion and smaller suck-down effects.

- Reingestion - Fan or gas generator inlet ingestion of both fan turbine hot gases or foreign objects is considered. Inlets well shielded from the ground or mounted well away from the ground are favored. Inlets in the proximity of possible ground reflection paths of high velocity hot gas exit flow, where circulation can occur, are downgraded. Gas generator inlet hot gas ingestion was rated more severe than fan inlet hot gas ingestion.

o Propulsion System Complexity - The number and size of fans and gas generators as well as associated equipment (doors, control, valves, starting systems, and vectoring systems) are important considerations. In general, the smaller the number of engines the better. Interconnect ducting requirements are an important discriminator for RLF configurations.

o Fuel Space Near cg - The fuel is carried in the wing between the front and rear spar. Therefore, this rating is based on wing size, planform, location of pods, and requirements for internal equipment.

o Landing Gear Length - The landing gear length is established to provide adequate ground clearance for structure (nacelles and lower fuselage) and the propulsion wake occurring in the vertical lift mode. Fuselage clearance is checked for aircraft rotation during rolling "takeoff" and "landing" modes of operation.

o Aeroelastic Problems - Wing aeroelastic stability and the dynamic load amplification factors become important considerations when using wing tip mounted lift fan pods. The primary variables used in the evaluation are pod surface area and shape; pod weight; location of the pod relative to the wing elastic axis; spanwise location of the pod; and sweepback angle of the wing.

o Reliability - The reliability evaluation was made on a comparative qualitative basis including considerations of type, quantity, and required activity of propulsion units for dispatch and redundancy available for safety; simplicity with which the units could be interfaced for control; method providing symmetrical thrust in the event of a failure; thrust-to-weight ratio; distribution of thrust; and flight control - the combination of which dictates potential problems, quickness of takeoff, effectiveness of control, and emergency requirements.

o Maintainability - The number and type of engines is an important factor. Lift/cruise engines are apt to have more service problems than pure lift or pure cruise engines. Accessibility is also a consideration, such as engines buried inside fuselage structure versus external nacelles.

o Internal Noise - Cockpit and cabin engine noise are of concern because of the high predicted levels which affect communication and annoyance. The noise levels are controlled by the size and acoustical treatment of the engines, their proximity to the crew and passengers, their time of operation (takeoff and landing being most critical to communication), and the transmission path of the noise into the compartments.

o External Noise - Aircraft engine noise measured in the far field is a function of the thrust, quantity, orientation of the engines, and acoustic treatment. An increase in thrust or in the number of engines will cause an increase in the overall aircraft noise. Engine orientation has varying effects depending on whether the inlets are pointed forward or up.

o Aesthetics (Customer Appeal) - The most appealing aircraft is generally the least radical in appearance; the one the customer has confidence in because it looks like something he has experience with and likes. Also, customer appeal is affected by its utility. It must be easily loaded with passengers, luggage, and cargo and easily serviced with fuel, food, etc.

The following are quantitative evaluation parameters:

o Propulsion System Lift T/W Installed (Total) - Preference is given to light weight propulsion systems.

o Thrust/TOGW - Total lift available at maximum VTO weight is calculated with all gas generators at takeoff power. (Intermediate 90°F SL). This parameter favors aircraft configured to efficiently use power.

o Fuel to GW Ratio (100 pax size) - This parameter rates efficiency for rapid takeoff and conversion and aerodynamic/propulsion cruise efficiency.

o V_{cruise} (Mach) - This parameter indicates conformance with mission requirement.

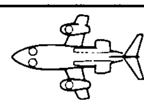
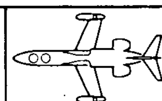
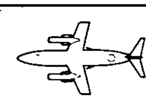
o Relative GW/Pax - This is an overall configuration efficiency factor. This parameter is a gross measure of relative economic factors.

PRELIMINARY EVALUATION AND CONFIGURATION SELECTION

Aircraft configuration variations considered in the evaluation included both high and low wings, four and six lift fans, and the use of wing tip fans for roll and roll/yaw control.

Based on a technical evaluation of the candidates shown in Figure B-1, the -6A, -6C, and the -4I were selected for further refinement and sizing to the mission. Significant physical, performance, and operational characteristics were determined and a comparative evaluation was conducted. The VT107-4-4I was selected as the best 4 engine candidate. Figure B-2 is the evaluation summary of the three final contenders.

FIGURE B-2
EVALUATION SUMMARY
4 ENGINE CONFIGURATIONS

CHARACTERISTICS	 VT 107-4-6A	 VT-107-4-6C	 VT107-4-4I
ENGINES	4	4	4
NOMINAL T/W (90°F, INSTALLED)	1.15	1.14	1.12
PERCENT MODULATION FOR CONTROL AT VTOGW	22	9**	20
GROSS WEIGHT RATIO	1.00	0.89	0.84
CRUISE MACH	0.75/0.78*	0.75/0.78*	0.75/0.77*
QUALITATIVE EVALUATION SCORE	51	61	63

* Maximum Mach Number Capability
** Roll and Yaw Control Provided by Wing Tip Control Fans

APPENDIX C - UPDATE OF 1972 STUDY AIRCRAFT

The 6 engine configuration selected in the 1972 study was updated to the new mission requirements and guidelines presented in Section 3 for a direct comparison with the selected 4 engine aircraft. The updated aircraft is shown in Figure C-1.

Figure C-2 summarizes the major physical and performance characteristics of the updated 6 engine design.

Figure C-3 shows the relationship of T/W ratio to cruise Mach number for the 6 engine configuration. Up to a Mach number of approximately 0.65 the propulsion system is sized by the emergency engine-out condition.

FIGURE C-1
6 ENGINE AIRCRAFT
TASK 1A M = 0.75 VT102-6-6C

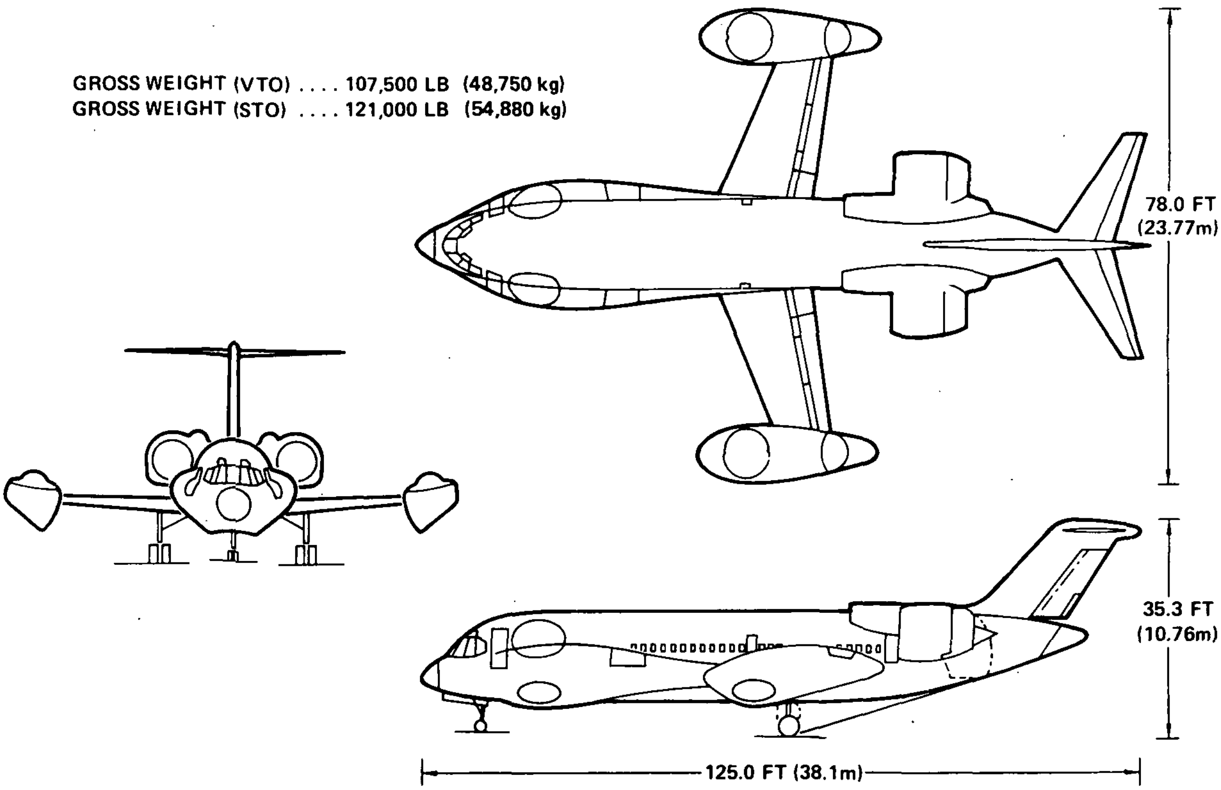


Figure C-2

Characteristics Summary
6 Engine Aircraft - Task 1A

VTO Gross Weight 400 nm (740 km)	107,500 lb (48,750 kg)
STO Gross Weight 800 nm (1480 km)	121,000 lb (54,800 kg)
Wing Loading at VTOGW	115 psf (562 kg/m^2)
Design Fan Pressure Ratio	1.37
Engines	6
Fan Diameter	76.0 in (1.93 m)
Nominal T/VTOGW at 90°F SL	1.19
% Modulation for Control (maximum)	24
Payload (100 passengers)	20,000 lb (9,072 kg)
Cruise Mach at 20,000 feet/V_{CRUISE} (MAX)	0.75/0.75
500 ft (150 m) Sideline Noise Level PNdB	99

Direct Operating Cost (1974 Dollars - Airframe at $90 lb, 3500 hr Utilization)

400 nm (740 km)	2.58¢/seat statute mile (1.60¢/seat km)
800 nm (1480 km)	2.13¢/seat statute mile (1.33¢/seat km)

	WING	HORIZONTAL TAIL	VERTICAL TAIL
S	935 ft^2 (87.0 m^2)	250 ft^2 (23.3 m^2)	200 ft^2 (18.6 m^2)
AR	5	5	.94
λ	.25	.35	.76
b	68.6 ft (20.9 m)	35.35 ft (10.8 m)	13.71 ft (4.19 m)
Λ C/4	22°	30°	42.8°
t/c	14%	8%	11%
AIRFOIL	Whitcomb Type Supercritical	DC-9 Type Empennage	DC-9 Type Empennage

FIGURE C-3
THRUST TO WEIGHT RATIO REQUIREMENTS
6 ENGINE AIRCRAFT

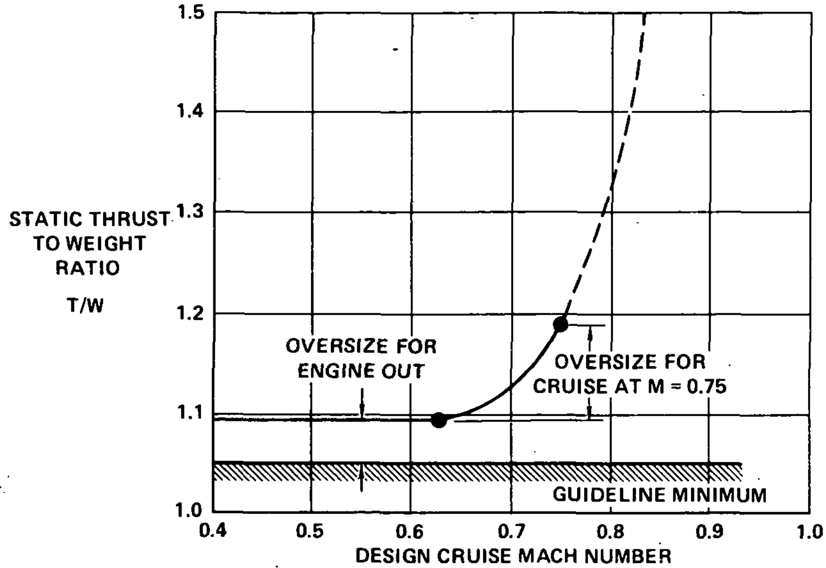


Figure C-4 presents the sized propulsion system data for the VT102-6-6C and VT VT102-6-6D (Task 2) aircraft. The 6 engine configuration, designated VT102-6-6D, is a scaled down version of the VT102-6-6C described in Section 4, and has a gross weight of 90,600 lb (41,100 kg). The propulsion system for this aircraft is sized for the engine out condition and needs no oversizing for the cruise speed of 0.65 M. The 6 engine aircraft resized for the cruise speed of 0.75 M is no longer competitive with the 4 engine aircraft.

The basic control concept of the VT102-6-6C is shown in Figure C-5. The 6 engine configuration requires a higher percentage of thrust modulation in roll than in pitch. This is typical of six fan aircraft arrangements where only one-third of the total lift is available from the wing units, and therefore the reference thrust is lower. The 4 engine aircraft, Figure 3.3-2, requires higher thrust modulation for pitch control than for roll. The nominal thrust level of the fuselage fans modulated for pitch control provides one-half of total aircraft lift as compared to two-thirds in the 6 engine concept. Therefore, a higher percentage of nominal thrust is used for control in the 4 engine configuration.

Yaw control is provided by differential deflection of the thrust of the fuselage fans as shown in Figure C-5. The deflection angle required is maximum at the lowest operating aircraft weight and consequently at a low nominal thrust level. Because only two of four fans are used for yaw control in the 4 engine configuration as compared to 4 of 6 in the 6 engine configuration, the deflection angle required is greater. However, even at full deflection, representing maximum yaw control input, the corresponding lift losses are only 0.033 g and 0.023 g in the 4 engine and the 6 engine aircraft, respectively.

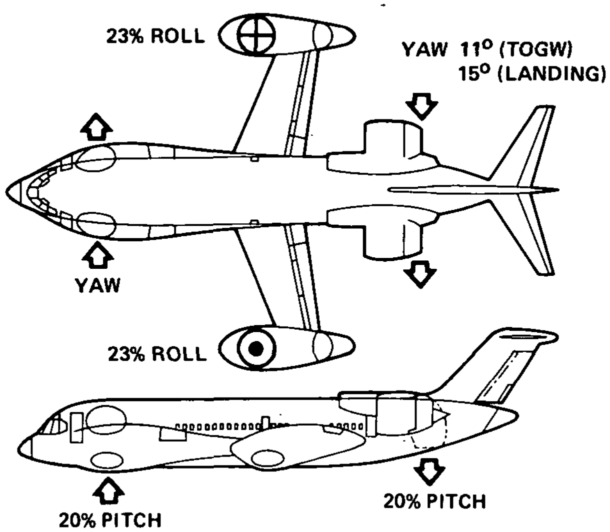
The methods of vectoring thrust for the 6 engine aircraft are described in Reference 1.

Figure C-4

Propulsion System Sizing and Performance
6 Engine Configurations

	VT102-6-6C	VT102-6-6D
GAS GENERATOR		
Thrust Scaling Factor	1.886	1.423
Scaled Gas Flow Rate - lb/sec (kg/sec)	127 (57.6)	95.8 (43.5)
Compressor Face Dia - in (cm)	28.0 (71.1)	24.8 (63)
Gas Geneator Length - in (cm)	67.2 (170.7)	59.3 (150.6)
FANS		
Design Pressure Ratio (100% N_f, SLS, Uninstalled)	1.367	1.367
Design Thrust Level Per Fan - lb (kg)	23,000 (10,400)	19,300 (8,800)
Fan Operating Pressure Ratio @ Intermediate, 90°F	1.334	1.31
Installed Thrust/Fan @ Intermediate, 90°F - lb (kg)	21,367 (9,712)	16,550 (7,522)
Fan Tip Dia - in (cm)	76.0 (193.0)	69.8 (177.3)
DUCT DIAMETERS		
Gas Generator to Fan (M_{MAX} = 0.3) - in (cm)	23.3 (59.2)	20.2 (51.3)
Interconnect Duct (M_{MAX} = 0.4) - in (cm)	14.6 (37.1)	12.7 (32.3)
VTOL INSTALLED PERFORMANCE		
Maximum VTO Thrust - lb (kg)	128,200 (58,200) (T/W = 1.193)	99,300 (45,000) (T/W = 1.09)
Emergency VTO Thrust (T/W = 1.03) - lb (kg)	110,800 (50,300)	93,500 (42,500)

FIGURE C-5
CONTROL REQUIREMENTS
VT102-6-6C



The DOCs calculated for the 6 engine aircraft, VT102-6-6C, which were used in the final evaluation for the Task 1A aircraft are shown in Figure C-6 along with those of the 4 engine VT107-4-4I. The latter is used as the baseline reference.

FIGURE C-6
DIRECT OPERATING COST COMPARISON
TASK 1A AIRCRAFT
1974 DOLLARS, 1968 AIA METHOD
UTILIZATION: 3500 HR/YR

AIRCRAFT MODEL	400 NM VTOL MISSION 460 STATUTE MILES OR 740 km				800 NM STOL MISSION 920 STATUTE MILES OR 1480 km			
	AIRFRAME COST				AIRFRAME COST			
	$90/LB ($198/kg)		$110/LB ($242/kg)		$90/LB ($198/kg)		$110/LB ($242/kg)	
	DIRECT OPERATING COST				DIRECT OPERATING COST			
	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE	¢/SEAT MILE (¢/SEAT km)	RELATIVE
BASELINE AIRCRAFT VT107-4-4I	2.573 (1.599)	1.0	2.680 (1.665)	1.0	2.138 (1.328)	1.0	2.231 (1.386)	1.0
VT102-6-6C	2.584 (1.606)	1.004	2.690 (1.671)	1.004	2.129 (1.322)	0.996	2.219 (1.379)	0.995

The DOCs of the Task 2 6 engine VT102-6-6D are compared to those of the 4 engine VT107-4-4K in Figure C-7. Again, the latter is used as the reference baseline.

FIGURE C-7
DIRECT OPERATING COST COMPARISON
TASK 2 SELECTED AIRCRAFT
1974 DOLLARS, 1968 AIA METHOD

AIRCRAFT MODEL	UTILIZATION (HR/YR)	200 NM VTOL MISSION (230 STATUTE MILES OR 370 km)			
		AIRFRAME COST $90/LB ($198/kg)		AIRFRAME COST ($110/LB ($242/kg)	
		DOC ¢/SEAT MILE (¢/SEAT km)	RELATIVE DOC	DOC ¢/SEAT MILE (¢/SEAT km)	RELATIVE DOC
VT107-4-4K	2500	3.544 (2.202)	1.0	3.705 (2.302)	1.0
VT102-6-6D		3.535 (2.197)	0.997	3.705 (2.302)	1.00
VT107-4-4K	3500	3.233 (2.009)	1.0	3.358 (2.086)	1.0
VT102-6-6D		3.194 (1.985)	0.988	3.325 (2.066)	0.99

APPENDIX D - FINAL EVALUATION SUMMARY

TASK 1A - 400 NM VTOL/800 NM STOL

The selected 4 engine V/STOL, shown in Figure D-1 and described in Section 2, and the updated 6 engine configuration, described in Appendix C were evaluated on both a quantitative and qualitative basis. Figure D-2 compares the major performance and operating factors and Figure D-3 is a detailed configuration comparison. Evaluation of these data leads to the selection of the VT107-4-4I over the the VT102-6-6C. The evaluation highlights the following superior characteristics:

o The selected aircraft price is 5% less even though gross weight is 5% greater. DOC is essentially equal. Airline investment is reduced.

o Propulsion system price is less even though propulsion system weight is increased. This is the result of fewer but larger units.

o The propulsion and control systems are simplified, thus contributing to improved dispatch reliability, maintenance, maintainability, and safety. Precise control capability and flying qualities have been retained.

o Passenger and luggage loading is more accessible.

o Cruise engines are on the wing, contributing to reduced cabin noise in cruise.

FIGURE D-1
1973 STUDY - CIVIL V/STOL TRANSPORT
4 ENGINE VT107-4-4I

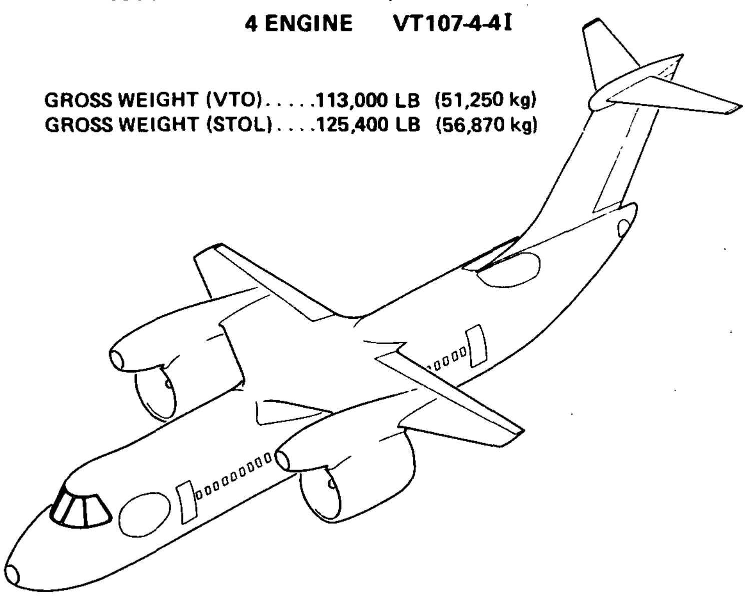


FIGURE D-2
SELECTED AIRCRAFT COMPARISON
TASK 1A M = 0.75

		4 ENGINE VT107-4-4I	6 ENGINE VT102-6-6C
VTOGW 400 NM (740 km)	(LB) (kg)	113,000 (51,250)	107,500 (48,750)
STOGW 800 NM (1480 km)	(LB) (kg)	125,400 (56,870)	121,000 (54,880)
NOMINAL T/W (90°F, INSTALLED)		1.20	1.19
FAN PRESSURE RATIO (DESIGN)		1.39	1.37
PERCENT MODULATION FOR CONTROL		28	23
CRUISE MACH (MISSION/MAX)		0.75/0.80	0.75/0.75
FLYAWAY COST RATIO		1.00	1.05
AVERAGE DIRECT OPERATING COST RATIO			
400 NM (740 km)		1.00	1.01
800 NM (1480 km)		1.00	1.00
95 PNdB - ACRES (SQ km)		44 (0.178)	43 (0.174)

FIGURE D-3
CONFIGURATION COMPARISON

THESE PARAMETERS TO BE GRADED QUALITATIVELY WITH RESPECT TO THE AIRCRAFT AS: GOOD (3) FAIR (2) POOR (1)	VT102-6-6C	VT107-4-4I
• CONTROL - ROLL	3	3
- PITCH % MODULATION REQUIRED	3	2
- YAW	3	3
• SIMPLE FLIGHT CONTROL SYSTEM	2.5	3
• SIMPLE CONTROL - ENGINE OR FAN OUT	2	2
• GROSS THRUST VECTORING RANGE AND METHOD	2.5	3
• AERODYNAMIC/PROPULSION INTERFERENCE EFFECTS	2	2
• CL_{MAX} (FLAP AFFECTED AREA)	3	3
• GROUND EFFECT	2.5	2
• REINGESTION	2	2
• PROPULSION SYSTEM COMPLEXITY	2	3
• FUEL SPACE NEAR CENTER OF GRAVITY	2.5	2
• LANDING GEAR LENGTH	3	2
• AEROELASTIC PROBLEMS	1.5	2
• RELIABILITY - SAFETY	2	3
- DISPATCH	2	3
• MAINTAINABILITY (NO. ENGINE AND ACCESS)	2	3
• NOISE - INTERNAL	2	2.5
• NOISE - EXTERNAL	2	2
• AESTHETICS (CUSTOMER APPEAL)	2	3
THESE PARAMETERS TO BE GRADED QUANTITATIVELY:		
• PROPULSION SYSTEM LIFT T/W INSTALLED (TOTAL)	2.5	2
• THRUST/TOGW	2	2
• FUEL TO GROSS WEIGHT RATIO (100 PAX SIZE)	3	3
• V_{CRUISE} (MACH)	3	3
• RELATIVE GROSS WEIGHT/PAX	3	2.5
TOTAL	60	63

TASK 2 - 200 NM VTOL STAGE LENGTH

The 4 engine aircraft (VT107-4-4K) configured and sized to the 200 nm VTOL mission requirement is described in Section 2.4 and shown in Figure 2-10. The 6 engine configuration (VT102-6-6D), a scaled down version of the VT102-6-6C is described in Appendix C. The direct operating costs for the VT107-4-4K are discussed in Section 3.5.2, and compared to the VT102-6-6D in Figure C-7 of Appendix C. It should be noted the cost data presented for the 6 engine aircraft applies only to a cruise speed of 0.65 M since the 6 engine aircraft is not considered competitive for the 0.75 M speed (see Appendix C). DOC for the VT102-6-6D and the VT107-4-4K aircraft are within 1%.

Figure D-4 is a performance comparison of the 4 engine and 6 engine Task 2 aircraft at cruise Mach numbers of 0.75 and 0.65, respectively; and Figure D-5 presents a comparison of qualitative factors. Based on these comparisons, the 4 engine VT107-4-4K was selected as the best solution for Task 2. Although DOCs are equal, the price of the -4K is 4% lower. The aircraft offers the same advantages in a simpler propulsion/lift/control system as presented for the Task 1 aircraft. Performance, propulsion, and control characteristics of the selected aircraft are discussed in Section 3.0.

FIGURE D-4
CONFIGURATION COMPARISON QUANTITATIVE FACTORS
TASK 2 - 200 NM (370 km)

	VT107-4-4K	VT102-6-6D
DESIGN MACH NUMBER	0.75(1)	0.65
VTOGW	96,400 LB (43,720 kg)(1)	90,600 LB (41,100 kg)
WING LOADING	115 PSI (560 kg/m^2)	115 PSF (560 kg/m^2)
FAN PRESSURE RATIO (DESIGN)	1.39	1.37
FAN DIAMETER	90.4 IN. (2.30m)	69.8 IN. (1.77m)
NOMINAL T/W AT 90°F (SEA LEVEL)	1.20	1.09
PERCENT CONTROL MODULATION AT TOGW	26	23
FLYAWAY COST RATIO	1.00	1.04
AVERAGE DIRECT OPERATING COST RATIO	1.00(2)	1.00
500 FT (150m) SIDELINE NOISE PNdB	98.1	97.9
CRUISE ALTITUDE (DESIGN)	25,000 FT (7,620m)	15,000 FT (4,570m)
QUALITATIVE EVALUATION SCORE	63	60

Notes:
(1) VTOGW Approximately same for M = 0.65. No Operating Advantage
(2) DOC for M = 0.65 Higher than for M = 0.75

FIGURE D-5
CONFIGURATION COMPARISON

THESE PARAMETERS TO BE GRADED QUALITATIVELY WITH RESPECT TO THE AIRCRAFT AS: GOOD (3) FAIR (2) POOR (1)	VT102-6-6D	VT107-4-4K
• CONTROL - ROLL	3	3
- PITCH % MODULATION REQUIRED	3	2
- YAW	3	3
• SIMPLE FLIGHT CONTROL SYSTEM	2.5	3
• SIMPLE CONTROL - ENGINE OUT	3	3
• GROSS THRUST VECTORING RANGE AND METHOD	2.5	3
• AERODYNAMIC/PROPULSION INTERFERENCE EFFECTS	2	2
• CL_{MAX} (FLAP AFFECTED AREA)	3	3
• GROUND EFFECT	2.5	2
• REINGESTION	2	2
• PROPULSION SYSTEM COMPLEXITY	2	3
• FUEL SPACE NEAR CENTER OF GRAVITY	2.5	2
• LANDING GEAR LENGTH	3	2
• AEROELASTIC PROBLEMS	1.5	2
• RELIABILITY - SAFETY	2	3
- DISPATCH	2	3
• MAINTAINABILITY (NO. ENGINE AND ACCESS)	2	3
• NOISE - INTERNAL	2	2.5
• NOISE - EXTERNAL	2	2
• AESTHETICS (CUSTOMER APPEAL)	2	3
THESE PARAMETERS TO BE GRADED QUANTITATIVELY:		
• PROPULSION SYSTEM LIFT T/W INSTALLED (TOTAL)	2.5	2
• THRUST/TOGW	3	2
• FUEL TO GROSS WEIGHT RATIO (100 PAX SIZE)	3	2
• V_{CRUISE} (MACH)	1*	3
• RELATIVE GROSS WEIGHT/PAX	3	2.5
TOTAL	60	63

*Cruises at M = 0.65 vs 0.75 Required

NASA-Langley, 1974